NAVAL BIODYNAMICS LABORATORY
NBDL-90R012

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THE EFFECTS OF FATIGUE ON 41-FT UTILITY BOAT CREWMEMBERS

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Research Report

May 1991

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Prepared for

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Volunteer subjects were recruited, evaluated, and employed in accordance with the procedures specified in Department of Defense Directive 3216.2, Secretary of the Navy Instruction 3900.39 series, and Bureau of Medicine and Surgery Instruction 3900.6 series. These instructions meet or exceed the provisions of prevailing national and international guidelines.

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave Blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1990	Interim

4. TITLE AND SUBTITLE

The Effects of Fatigue on 41-ft Utility Boat Crewmembers

5. FUNDING NUMBERS

Z51100-9-0013

6. AUTHOR(S)

T. R. Morrison, S. C. Webb, and R. M. Wildzunas

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Naval Biodynamics Laboratory
P. O. Box 29407
New Orleans, LA 70189-0407

8. PERFORMING ORGANIZATION REPORT NUMBER

NBDL-90R012

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

U.S. Coast Guard Research and Development
Marine Systems Branch
Avery Point
Groton, CT 06340

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The U. S. Coast Guard (USCG) is concerned that prolonged boat operations may produce excessive fatigue, which can contribute to accidents and injuries and degrade operational capability. This study assesses the effects of fatigue on 41-ft Utility Boat (UTB) crewmembers. Twenty USCG UTB crew members participated. Four-man crews were trained to baseline then tested, seated in the below cabin, every two hours during 16-hr simulated missions in both calm and heavy seas. Performance tests included tracking, four-choice reaction, addition, memory and search, and manual assembly tasks. Subjective tests included mood and motion sickness questionnaires. Tests were administered via a computer, using a visual display or appropriate manual input devices. *Fatigue plus motion* increased response times to the four-choice, memory and search, and manual assembly tasks during hours 9-16 at sea. Tracking performance declined sharply during the first two hours, then continuously improved during hours 3-16. The mood scales indicated progressive increases in negative effect for fatigue, sleepiness, depression, activity feelings, and happiness. Motion sickness increased during the mission and with heavy seas. These results generally support the crew scheduling guidelines specified in USCG COMMANDANT INSTRUCTION 5312.15A, which limit cumulative crew underway time during a 24 hr period to 10 hrs for 0-4 ft seas and 8 hrs for 4-8 ft seas.

14. SUBJECT TERMS

Fatigue; sustained operations; performance; stress.

15. NUMBER OF PAGES

49

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std Z39-18
298-102

EXECUTIVE SUMMARY

The U.S. Coast Guard has identified fatigue as a factor that adversely affects boat crew operational capability and safety. Fatigued boat crews make judgmental errors and show decreased coordination, reduced attention spans, and diminished performance. A high percentage of mishaps has been associated with prolonged operations and crew fatigue (COMMANDANT INSTRUCTION 5312.15A).

The Naval Biodynamics Laboratory employed a battery of human performance tests to assess the effects of fatigue on crew performance during 41-ft Utility Boat (UTB) missions. Simulated 16-hour search and rescue patterns were conducted both in seas greater than 4 ft (1.2 m) and in seas less than 4 ft. Five performance tests were selected for this study: a tracking task that models many of the perceptual-cognitive demands encountered in steering a vessel such as the UTB; a four-choice reaction time task, which simulates simple choices where specified responses are required, such as recognizing a day shape and performing the appropriate response; a memory and search task, which requires a person to remember certain target information and search a display for that information, as an operator would do in using a map or a radar display; a manual assembly task, which requires rapid assembly of various sizes of nuts, washers, and bolts, and is similar to manual tasks required during underway repairs; and a two-column addition task, which requires mental numerical performance similar to mental computations used by a coxswain to determine a vessel's true heading. In addition to these five performance tests, a motion sickness symptomatology checklist, a motion sickness magnitude estimate, a motion magnitude estimate, a sleep scale, and a mood scale were employed to measure subjective correlates of motion and fatigue.

Results from three of the five performance tests indicated that fatigue *plus motion* degraded task performance. These decrements occurred during the 9–16 hour period of the 16-hour mission. The subjective measures of fatigue — sleepiness, depression, activity, and happiness — progressively increased (or decreased) in a systematic manner during the mission. The present results support the boat crew scheduling guidelines specified in COMMANDANT INSTRUCTION 5312.15A.

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THE EFFECTS OF FATIGUE ON 41-FT UTILITY BOAT CREWMEMBERS

INTRODUCTION

STATEMENT OF PROBLEM

The U.S. Coast Guard believes that fatigue may be a principal factor that adversely affects boat crew operational capability and safety. Fatigued boat crews make judgmental errors and show decreased coordination, reduc. ttention spans, and diminished performance. A high percentage of mishaps has been associated with prolonged operations and crew fatigue [1].

The U.S. Coast Guard has defined fatigue as follows:

> Fatigue — A condition of impaired mental and physical performance brought about by extended periods of exertion and stress which reduces the individual's capability to respond to external stimuli. Some factors contributing to fatigue are sleep loss, exposure to temperature extremes (hypothermia and heat stress), motion sickness, changes in work and sleep cycles, physical exertion, anxiety, work load, illness, dehydration, hunger, personal problems, and boredom [1].

BACKGROUND

In an effort to reduce the degradation of boat crew performance resulting from fatigue, the U.S. Coast Guard issued COMMANDANT INSTRUCTION 5312.15A [1]. This instruction established boat crew scheduling guidelines to be used by District Commanders and includes the maximum number of underway hours allowed during a 24 hour period for a single crewmember. In establishing boat crew utilization guidelines, District Commanders were instructed to consider the cumulative effects of fatigue-inducing factors (heavy weather, temperature, boat motion), operational factors (distance off shore, type and duration of mission, open versus closed vessel, forecasted weather), and human factors (i.e., motion sickness, survival clothing, changes in sleep and work cycles, work-duty time).

Proper crew scheduling is difficult. Ideally, the Commander should consider all the fatigue-inducing factors and adjust the cumulative underway time accordingly. Consequently, fatigue could be controlled. The problem is that performance decrements as a function of the above variables within the U.S. Coast Guard boat operations context are not known.

Royal and Needalman [2] obtained self-report, cognitive, performance, and physiological data during Coast Guard boat operations to develop quantitative measures on crew fatigue that could be used to assess the effectiveness of boat crew duty schedules and to support the development of new crew utilization guidelines. No cognitive or performance changes as a function of crew time underway were obtained. Self-report ratings for items such as "drowsy," "fatigued," and "run-down" varied directly with crew time underway. Ratings for items such as "enthusiastic" and "energetic" varied inversely with crew time underway. Visual contrast sensitivity data for the "E-target" showed degradation attributed to crew time underway.

As noted by Royal and Needalman [2], problems occurred using the Automated Portable Test System (APTS), which was implemented via a NEC PC 8201A laptop microcomputer. During test administration the NEC computer ". . . was positioned either on the chart table or on the lap of the seated crewmember." The NEC PC 8201A was not secured and it was difficult for crewmembers to hit the correct keys under rough seas. The investigation conducted by the Naval Biodynamics Laboratory utilized an at-sea test station (described below), which was secured both overhead and to the below-cabin deck. This system allowed more standardized test conditions at sea and was designed to reduce many sources of error variance, thus providing a more sensitive assessment of at-sea performance.

TECHNICAL APPROACH

The following study was performed to identify better fatigue problems in Coast Guard small boat operations.

Mission Analyses

Boatcrew Qualification Guides for the coxswain, boat crewman, engineer, and surfman were reviewed. U.S. Coast Guard personnel were interviewed and onboard 41-ft Utility Boat (UTB) underway job analyses were performed at the U.S. Coast Guard Canal Unit, New Orleans, LA. Additional useful information concerning Coast Guard UTB missions and duty schedules currently used by four U.S. Coast Guard units was provided by Royal and Needalman's study [2].

Simulation Versus At Sea

An important consideration was whether to perform the study in the Naval Biodynamics Laboratory (NAVBIODYNLAB) Ship Motion Simulator (SMS) or at sea. The SMS is an established research tool used to assess performance under various motion conditions. The NAVBIODYNLAB SMS has recently been configured with equipment and software to permit administration of the Unified Tri-Service Cognitive Performance Assessment Battery (UTC-PAB) [3]. However, a major concern of this investigation was not merely the effects of motion on performance, but the need to assess the effects of fatigue in the 41-ft UTB on human performance. Consideration was given to the possibility of using the Marine Institute of Technology and Graduate Studies (MITAGS) Simulator rather than the SMS. However, since it would probably be impossible to adequately simulate the multitude of fatigue-causing variables in either the SMS or the MITAGS simulator, our technical approach was to perform the investigation at sea, during actual Coast Guard missions.

Relevant Tasks Selected for Study

Based on our mission and task analyses, the following set of performance tests and questionnaires was selected to assess fatigue while underway in the 41-ft UTB.

Tests:
1. Critical Instability Tracking Task
2. Four-Choice Reaction Time Task
3. Memory and Search Task
4. Manual Assembly Task
5. Two-Column Addition Task
6. Stanford Sleepiness Scale
7. Mood II Questionnaire
8. Motion Sickness Symptomatology Checklist
9. Motion Sickness Magnitude Estimate
10. Motion Magnitude Estimate

The selected tests require many of the cognitive and perceptual abilities thought to be essential in performing Coast Guard boat tasks. The Critical Instability Tracking Task requires psychomotor eye-hand coordination skills that the coxswain uses in steering the boat. The Four-Choice Reaction Time Task measures the time used to make a simple decision and the accuracy of response. The two tests also provide measures of continuous and discrete motor task performance, respectively. The Memory and Search Task is similar to searching navigational maps for known buoy numbers or markers; it measures the time and accuracy of a search for two memorized target letters from a string of letters. The Manual Assembly Task, which involves the assembly of nuts, washers, and bolts in various ways, is thought relevant to some types of underway mechanical repair tasks. The coxswain, during execution of various search patterns, must mentally compute the next heading; hence the inclusion of the Two-Column Addition Task.

The Stanford Sleepiness Scale and the Mood II Questionnaire are useful in detecting changes in how a person feels, as opposed to actual performance changes. Similarly, the Motion Sickness Symptomatology Checklist and Motion Sickness Magnitude Estimates are useful since motion sickness may affect a crewmember's performance. The questionnaires, estimates, and checklists were administered during the same test sessions as the performance tests.

RELEVANT RESEARCH FINDINGS

The following is a review of literature relevant to the fatigue investigation. A satisfactory textbook definition of fatigue is hard to find; although the term is used extensively, it is rarely defined. Since a multitude of variables may contribute to fatigue and result in degraded performance, only those considered most relevant to the present research are presented below.

Berkhout [4] identified fatigue as an aspect of stress, affected by stressor conditions such as mechanical work overload, perceptual stimulus anomalies, or the disruption of circadian rhythms, including sleep deprivation. Holding [5] demonstrated that fatigue negatively affects skill performance and presented two different aspects of fatigue: deterioration of performance on a prolonged task, and the more elusive results of earlier fatigue on subsequent tasks.

Blum and Naylor [6] defined a number of physiological and psychological aspects of fatigue. Physiological effects are evident from the increased recovery time of a muscle that has been forced to work repeatedly. Psychological factors included task monotony, inadequate sleep, inefficient work spaces, length of sustained attention, length of work period, and inefficient work methods.

Tracking Task Duration

Ellingstad and Heimstra [7] exposed subjects to a primary tracking task and a variety of subsidiary tasks for a total duration of 15 hours. Tracking performance was assessed through the use of two error measures: amount of time off the target track and number of times off target. A significant decrement in tracking performance, as a function of time, was obtained for both measures.

Motion

McLeod, Poulton, Ross, and Lewis [8] investigated the effects of ship motion on three manual tasks: tracing, pursuit tracking, and digit keying. The motion produced a vertical root mean square (RMS) acceleration of 0.024 g, largely between 0.1 and 0.3 Hz, with little roll or pitch. Peak-to-peak vertical motion was 2.5 m. Tracing performance with no arm support and pursuit tracking with arm support were degraded under motion. Because pursuit tracking error measures remained constant during the 50-minute motion test period, and motion sickness ratings indicated only a 9% increase in one of nine symptoms, the authors concluded that the pursuit tracking decrements were due to motion, not motion sickness. Digit keying performance was unaffected by motion.

As noted, manual tracking was found to be affected by time on task and by motion. Both independent variables are relevant to the present research. The required experimental approach must address the problem of specific effects on tracking performance due to motion (McLeod et al. [8]) and due to fatigue (Ellingstad and Heimstra [7]).

Vibration — motion in the frequency range from 10–30 Hz — was reported by Grether [9] to degrade human performance. Visual acuity was shown to be severely impaired by vibration frequencies in the range of 10–25 Hz. Manual tracking capability was most seriously affected by vibrations at 5 Hz and below. Tasks primarily involving central neural processes, such as reaction time, monitoring, and pattern recognition, were highly resistant to effects of vibration.

Prior Exercise

Hammerton and Tickner [10] investigated the effects of prior exercise on an acquisition tracking task. After tracking performance had stabilized, subjects were required to step up and down on a 12-in (30.5 cm) step 200 times in seven minutes. Their stabilized acquisition tracking times of 19 seconds increased to 34 seconds following exercise. Another study by Hammerton and Tickner [11] provided evidence that fatiguing the thumb via repetitive maximum exertions produced poorer tracking performance in a thumb joystick tracking task.

Heat

Poulton [12] summarized a number of studies that showed decrements in performance as a function of exposure to increased levels of ambient heat. Task performance degraded by heat included: telegraph reception, heavy pursuitmeter, coding, vigilance, and the Five-Choice Task. The Five-Choice Task was performed in a temperature of 100 °F (38 °C). Errors increased, as did frequency of response times longer than 1.5 seconds. Both effects were present in the first five minutes of the task. Bell [13] investigated the effects of ambient heat and noise on pursuit tracking (primary task) and on a comparison of auditory digits (secondary task). More errors were made on the auditory task as the temperature increased from 22 to 35 °C. Higher noise level resulted in more errors. The two effects were independent. Reaction times in a four-choice reaction time task were longer under 37 °C versus 22 °C [14]. An important consideration concerning heat effects on performance is that humans acclimatize and develop considerable tolerance to heat. The tolerable limit of exposure to heat stress is almost entirely a function of prior acclimatization and required workload [4].

Cold

Adaptation to cold includes circulatory changes that limit the exchange of heat with the external environment. Cutaneous blood vessel constriction results in reduced peripheral blood flow. Shivering interferes with hand strength, fine motor control and coordination, and tactile ability. Vision and hearing acuity appear not to be affected [4]. Ellis [15] found that choice reaction time errors increased significantly during a 1.5-hour exposure to a mean ambient temperature of −12 °C.

Circadian Rhythm

Folkard and Monk [16] summarized findings from a number of studies which indicated that performance of perceptual-motor tasks improved over most of the day, while short term memory showed a general decline. They presented data from a previous study which found that performance on the Memory and Search Task (MAST) with two memory items paralleled body temperature. However, MAST performance with six memory items showed a very different trend relative to body temperature and improved during the night shift (2200–0600). These researchers [17] presented consistent evidence from three studies that showed immediate memory performance improved from 0900 to 1100, then generally declined until 1700. Englund, Ryan, Naitoh, and Hogdon [18] found performance on the Four-Choice Reaction Time Task to be worse in the early morning (0230). Their results showed logical reasoning to be at its lowest from 2240 to 0215. Morgan, Brown, and Alluisi [19] reported large decrements in synthetic work performance occurring during the early morning hours (0200–0600).

Sleep Deprivation

Haslam [20] investigated the effects of sleep loss during a nine-day exercise that included performance on a variety of tasks. Haslam's results indicated that performance on a vigilance shooting task was degraded during the first three days without sleep. Logical reasoning and decoding performance progressively deteriorated during that time. Englund et al. [21] reported that visual vigilance performance and shape memory were degraded by sleep deprivation. Synthetic work performance has been shown to decrease significantly during a 48-hour period of continuous work [19].

METHOD

SUBJECTS

A total of 20 male Coast Guard 41-ft UTB crewmembers participated in the NAVBIODYNLAB study. Each of the following Coast Guard stations provided one group of four crewmembers: New Orleans, LA; Port Aransas, TX; and Galveston, TX. Coast Guard Station San Francisco, CA provided two groups (four each). Each group consisted of one qualified coxswain, sometimes a coxswain in training, one or two general boat crew, and/or an engineer. The mean age was 24 years 11 months; range was 20 to 33 years.

EQUIPMENT

Performance and Questionnaire Testing Equipment

With the exception of the computer, the test equipment was as prescribed for the UTC-PAB. Due to the anticipated severe motion environment, a shock-tested Texas Microsystems, Inc. (TMI) computer was used. The TMI was equipped with a 10 MHz clock, a Sigma Designs Color 400-SH board, and a Systems Research Laboratory SRL-Labpac multi-function board. The Stimulus Equipment Company's Mini-Modulus III is a standardized subject response panel produced specifically for the UTC-PAB. The Modulus III response panel contained three interchangeable modules: a tapping key, a 180° resistive (proportional output) joystick, and a numeric keypad (two keys were labeled "S" for "same" and "D" for "different"). The response panel was configured so that the numeric keypad was on the right, the joystick in the center, and the tapper switch on the left. The tests and questionnaires were presented on a Princeton Graphic Systems SR-12 RGB color monitor.

Figure 1 illustrates the test equipment configuration aboard the UTB. The test equipment support structure consisted of four metal posts and cross members, which were fitted with horizontal metal plates that supported the computer, monitor, Modulus III response panel, and motion measurement system. The top ends of the posts were fitted with pressure plates that attached to threaded shafts; when sufficiently extended, the plates made friction contact with the cabin ceiling and rigidly held the equipment support structure in place. The bottom ends of the posts were attached to a metal plate that was securely clamped to the hull reinforcement stringers via the circular opening in the below cabin deck. The test station included in the below cabin a chair that faced aft. The base of the chair was securely attached to the deck metal plate. The subject's VDT, response panel, and chair were configured in accordance with established human engineering design guidelines [21]. The test chair was a standard Turnbull shipboard workstation chair (Model 31472-5), which provided 6 inches (15.24 cm) vertical and 7 inches (17.78 cm) fore-aft movement to accommodate different size subjects and produce a well designed human performance testing station. An invertor was installed aboard the UTB to produce the 110 V AC power required for the test equipment. (The available UTB power was 26 V DC). An uninterruptible power supply was connected to the invertor and provided power to all test equipment.

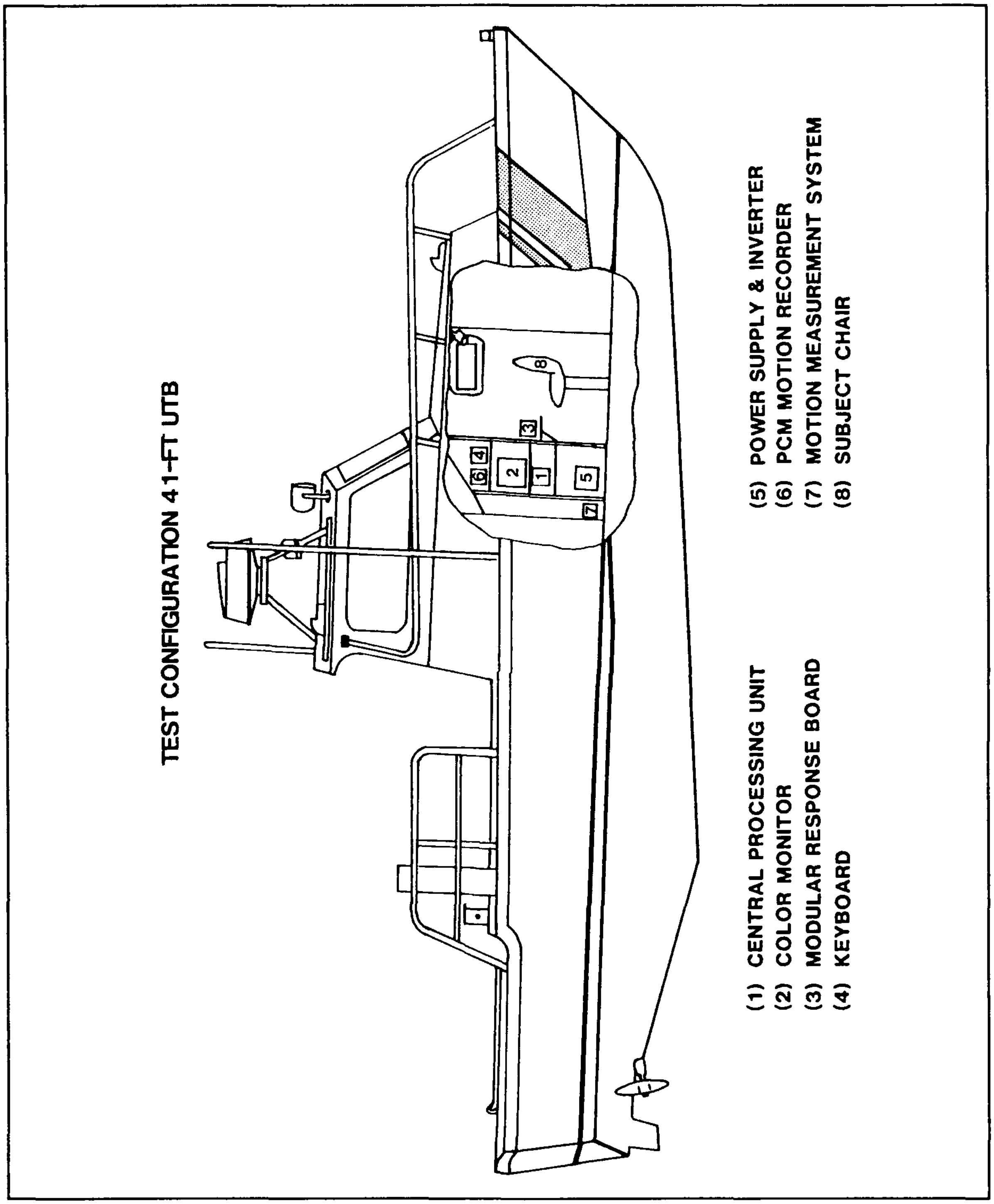

Figure 1. Testing equipment configuration aboard the Coast Guard 41-ft Utility Boat.

At Sea Motion Measurement System

The NAVBIODYNLAB motion measurement system consisted of a sensor package and a TEAC RD-101T high-density multiplex PCM data recorder. The recorder automatically recorded the time codes, voice memos, counter values, and data numbers on other dedicated, independent channels. The motion sensors included three accelerometers that were aligned with the heave, longitudinal, and transverse axes and three rate sensors that measured pitch, roll, and yaw angular rates. Temperature, humidity, and dBA noise level were measured during the test administrations.

TEST/QUESTIONNAIRE BATTERY

The performance tests were chosen to emulate the kinds of cognitive and behavioral demands imposed upon UTB operators. Four of these tests are from the UTC-PAB: Four-Choice Reaction Time, Critical Instability Tracking, Two-Column Addition, and Memory and Search. The Walter Reed Army Institute of Research Performance Assessment Battery (WRAIR-PAB) Four-Choice Reaction Time Task and Memory and Search Task [22], as well as the System Research Laboratory version of the Critical Tracking Task [23], were used. The Tracking Task and the Four-Choice Reaction Task have been found to be sensitive to performance decrement during sustained operations. The Two-Column Addition Task has been shown to be sensitive to sleep deprivation. Greater detail on the UTC-PAB is beyond the scope of this report and interested parties are directed to other sources [3, 24].

In addition to these, five scales provided subjective assessment of sleepiness, motion sickness, motion magnitude, and mood states that may be related to UTB performance changes. The Manual Assembly Task, Motion Sickness Symptomatology Checklist, Motion Magnitude Estimation, and Motion Sickness Estimation Questionnaire were developed at the NAVBIODYNLAB. The test battery also included the Stanford Sleepiness Scale and the Mood II Questionnaire, which are part of the UTC-PAB.

The time required to complete the test battery once was approximately 18 minutes.

Critical Instability Tracking Task (CITT)

The software for this task was produced by the System Research Laboratory (SRL) for use by UTC-PAB participating laboratories [23]. This task places demands on human information processing and manual dexterity. The display consists of a stationary horizontal white line with vertical "walls" at each end, a red triangle centered below the line, and an inverted white triangle above the line. A trial starts when the white triangle moves horizontally either right or left from center. The task is to keep the white triangle cursor centered over the stationary red triangle by manipulating the joystick. The instability of the task is activated by the subject's movement of the joystick and a predetermined initial error value. When the subject attempts to maintain the centered position, the error — the number of degrees the cursor is off center — is recorded, transformed, and then added back into the system to increase the movement of the cursor. When the cursor hits either wall, it is automatically reset to the center position and after one second begins to move again. The performance scores are determined by root mean square (RMS) of cursor deviations from the fixed cursor, number of wall hits, and final Lambda value. Lambda is a task difficulty index, in that the cursor deviation from center is multiplied by the Lambda value to determine the next cursor position. In the tracking task defined in this experiment, the initial low Lambda was set at 2.0; the high Lambda was set at 10.0. The task duration was four minutes. The Lambda increment is a function of the low and high Lambda settings and the task duration. The Lambda decreased by 3% following each wall strike.

The cognitive behavioral demands of the CITT are similar to the task demands involved in steering a UTB. The coxswain performs a similar activity when using the helm to maintain the alignment of the desired UTB heading with the compass lubber line. Steering the UTB and performing the CITT are manual control tasks that require continuous eye-hand coordination.

Four-Choice Reaction Time Task

This task is described by Englund et al. [3]. It is a modification of the Four-Choice Reaction Time Task developed by Wilkinson and Houghton [25]. During the task a plus sign ("+") appears in one of four quadrants on the monitor screen. The subject is instructed to press the key (one of four on the keypad) that spatially corresponds to the screen quadrant in which the plus sign appears. The plus sign remains visible until the subject presses one of the four keys. Immediately after the key press, the plus sign randomly reappears in one of the four quadrants. Subjects are instructed to respond as quickly and accurately as possible. Each test interval contains 32 stimulus trials or lasted 180 seconds, whichever occurs first.

During a mission crewmembers are often required to perceive a situation, decide what the correct response should be, and execute that response. The Four-Choice Reaction Time Task represents a simple decision-response task similar to many perceptual tasks that involve identification of visual patterns (such as buoys, day shapes, and night lights) and execution of the appropriate response. The motor responses used to press the appropriate button during the task are similar to those necessary to correctly select radio channels. The Four-Choice Reaction Time Task has been used effectively in a number of studies investigating fatigue, sleep deprivation, and vigilance.

Memory and Search Task

This task is described by Thorne, Genser, Sing, and Hegge [22]. Two target letters are presented at the top of the monitor screen; simultaneously a row of 20 letters appears in the middle of the screen. The task is to determine whether both target letters are present in the row of 20 letters. If both target letters are present, in any order, the subject presses the "S" (for "same") key on the keypad. If both letters are not present, the subject presses the "D" (for "different") key. Both the target and search row letters change with each trial. Accuracy and reaction time are measured. Subjects are instructed to respond as quickly and accurately as possible. Each test interval consists of 32 stimulus trials, or 180 seconds, whichever comes first.

This task was selected because radar operators perform a similar task when searching the scope for particular targets while remembering the target information. Similarly, a crewmember searching a chart for a particular target is required to maintain target information in memory while visually searching the chart.

Manual Assembly Task

The Manual Assembly Task is designed to assess manual dexterity and fine motor control. This test utilizes a 7 x 6-in (17.8 x 15.2-cm) vertical metal plate fitted with a row of three 1/4-in (6.35-mm) diameter threaded studs near the top edge and a row of three 1/4-in diameter threaded holes near the bottom edge. The subject is instructed to screw the nuts on the studs and the studs into the holes "hand tight snug." Three cloth bags are secured to the lower edge of the plate; one bag contains washers, one contains nuts, and one contains bolts. A subject first starts the clock by pressing the tapper switch, then places a washer on a stud and screws on a nut behind it. This is repeated for two other studs, and then the tapper is pressed again to stop the clock. This establishes the time to complete the first row. For the second part of the task, the subject places a washer on a bolt and screws the bolt into a threaded hole, repeating this process for two other holes; then presses the tapper a final time. The computer measures the average time to complete each row and the overall elapsed time. In this experiment, the plate is attached to the equipment support structure to the right of the Modulus III panel. The subject can use one or both hands; however, he is instructed to "always perform the task in the same manner."

The Manual Assembly Task simulated certain movements necessary to perform underway mechanical repairs on the UTB. Also, the Manual Assembly Task simulates various types of fire hose assembly tasks required in fire fighting operations.

Two-Column Addition Task

This test is described in England et al. [3]. It is a mental arithmetic test that measures the ability to perform (in one's head) simple addition problems with speed and accuracy. In this test a set of five two-digit numbers is presented simultaneously in a column format in the center of the screen. The subject is required to sum the digits as rapidly as possible and enter the "tens" digit (second digit from the right) via the keypad.

An example of UTB tasks relevant to this mental addition test is the mental computation involved in determining the next required heading during a particular UTB search pattern. Another example concerns compass error, the angular difference between a compass direction and the corresponding true direction. The compass reading must be corrected for variation and deviation. The mental computations required to perform the Two-Column Addition Task or correct a compass heading by adding or subtracting variation and deviation are similar.

Stanford Sleepiness Scale

The Stanford Sleepiness Scale is a seven-item scale which requests that the subject report how he is feeling at the particular time (see Hoddes, Zarcone, Smythe, Phillips, and Dement [26]). This scale is sensitive to fatigue, sleepiness, and time-of-day effects. It has been used successfully in military settings.

Mood II Questionnaire

The Mood II Questionnaire includes 36 mood descriptions that identified six dimensions of mood: activity, anger, fatigue, fear, happiness, and depression. To each descriptor word the subject enters either "0" for "not at all," "1" for "somewhat or slightly," or "2" for "mostly or generally," according to how he feels at that time. This test has been used in military environments investigating sleep logistics and fatigue.

Motion Sickness Symptomatology Questionnaire

The motion sickness questionnaire is a checklist consisting of 24 words which describe subjective responses to motion sickness symptoms. Included are self ratings on a scale of 0–3 (0 = not at all, 1 = slight, 2 = mild, 3 = sever) for symptoms such as dizziness, general ill feelings, headache, sleepiness, stomach awareness, fatigue, nausea, sweating, dry heaves, difficulty in concentrating, and vomiting.

Motion Sickness Magnitude Estimation

The subject was instructed to indicate on a scale of 0 to 9 (0 = not at all, 9 = severe) an overall rating of his feelings and symptoms of motion sickness.

Motion Magnitude Estimation

The subject was instructed to estimate, from 0 to 9 (0 = not at all, 9 = severe), the amount of motion he presently perceives.

PROCEDURES

The calm sea (less than 4-ft wave height) procedures were performed on Lake Pontchartrain, north of New Orleans, LA, beginning in mid-February 1990. Crews rotated weekly for five consecutive weeks. The protocol consisted of the following: Each group of four crewmembers arrived in New Orleans on Sunday, performed baseline tests Monday through Thursday, at-sea tests on Friday, post-recovery tests on Saturday afternoon, and then departed.

After completion of calm sea procedures, the test equipment was removed from the New Orleans UTB and shipped to San Francisco, CA, where it was installed on the San Francisco UTB. Heavy sea (greater than 4 ft) procedures were performed in the "Potato Patch" area immediately outside San Francisco Bay. Testing began the second week in May 1990. The same five crews were tested, in the same order, one group per week. Baseline tests were conducted on Monday and Tuesday, at-sea tests on Wednesday, and post-recovery tests on Thursday.

During the Lake Pontchartrain procedures, the scheduled Friday at-sea operational simulation for one group was postponed a day due to bad weather. This group received an additional baseline training day on that Friday, followed by the at-sea test on Saturday and post-recovery test on Sunday. Similarly, during the San Francisco procedures, the at-sea operational simulation for one crew was terminated prematurely due to exceedingly heavy seas. The crew was allowed to rest the following day (Thursday), and completed the operational simulation on Friday; post-recovery tests were conducted on Saturday.

Prior to each session, a questionnaire was administered to each subject to gather information on the amount of sleep obtained the night before, drug usage (e.g., alcohol, caffeine, cigarettes, and medication), and meals consumed.

Baseline Performance Testing

Each subject received four days of baseline tests prior to the Lake Pontchartrain 16-hour at-sea operational simulation and two baseline test days prior to the San Francisco Bay

16-hour at-sea operational simulation. During each baseline day each subject was tested during a 1-hour session in the morning and another in the afternoon. Sessions began on the hour, from 0700 to 1100; lunch was taken from 1100 to 1200; and afternoon tests were conducted from 1200 to 1600. Each subject was tested at each of the four morning and afternoon sessions. For example, Subject A was tested at 0700 and 1200 Monday; 0800 and 1300 Tuesday; 0900 and 1400 Wednesday; and 1000 and 1500 Thursday. During each one hour session each subject performed the test battery twice.

Baseline testing was performed dockside on the New Orleans Industrial Canal at Coast Guard Group New Orleans, LA and at the Coast Guard Station San Francisco on Yerba Buena Island, CA.

At-Sea Testing

Two 16-hour simulated operational missions at sea were designed by the Coast Guard, one for Lake Pontchartrain (see Figure 2) and one for San Francisco Bay (see Figure 3). Each mission included a variety of speeds and headings to be steered during each part of the mission, at a particular time of day. During each mission, the crew executed expanding square search, vector search, and parallel search patterns. Each 16-hour mission got underway at 0700 and continued through 2300. Immediately after getting underway, the first subject began the test battery. The second subject began at 0730, third at 0800, and forth at 0830. This cycle was repeated every two hours, so that each subject completed the test battery eight times during the 16-hour period.

The motion measurement system was turned on at the beginning of the mission and ran continuously for two hours. During the remainder of the at-sea test day, the motion recorder was activated for 10–15 minute intervals when the wave conditions and/or UTB speed and course were changed. Temperature, humidity, and DBA noise level were measured routinely on the hour during the test administrations.

Post At-Sea Testing

Immediately following each mission, the UTB was secured dockside at the station and each crewmember was tested in the same order as during at-sea tests. This measurement should reflect fatigue effects isolated from the motion effects; whereas, at sea, the test data should be influenced by both motion effects and fatigue effects. Since it was not possible to test all the duty boat crew simultaneously, members not being tested were required to go about their other normal duties until being tested; however, no sleeping was allowed. Each person was administered the battery once, then allowed to return to quarters to sleep.

Recovery Baseline Testing

The subjects were administered the test battery once following a minimum of 10 hours rest and recovery. These data should reflect performance following rest, and should be comparable to the baseline performance.

Sea States

The goal of this study was to administer the at-sea testing to the same individuals under Calm Sea (Lake Pontchartrain) and Heavy Sea (San Francisco Bay) states. Calm sea state was defined on the lake as seas with waves no greater than 4 ft. Heavy Sea state outside

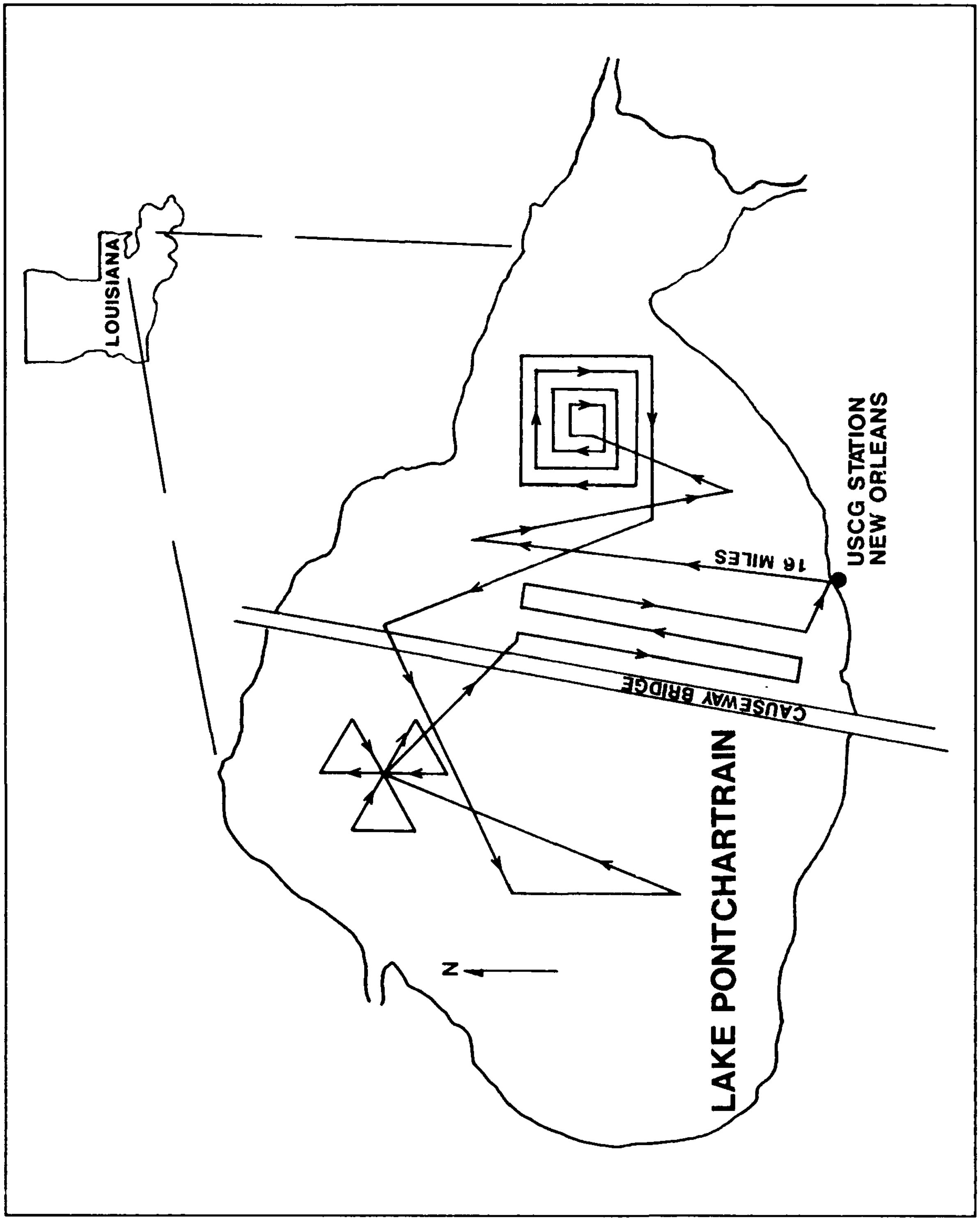

Figure 2. Calm sea (Lake Pontchartrain) operational simulation.

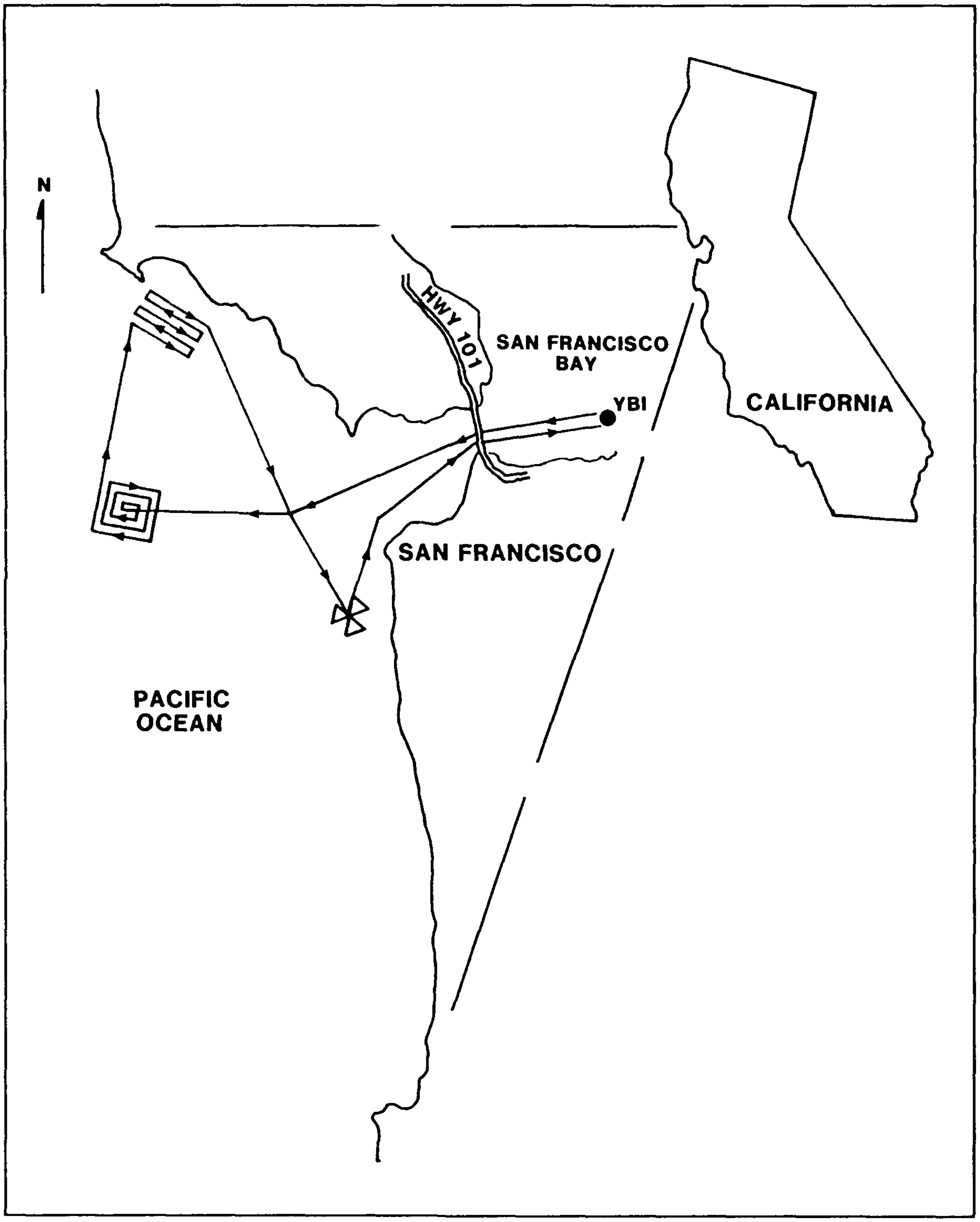

Figure 3. Heavy sea (San Francisco Bay) operational simulation.

the bay was defined as seas with swells and waves no less than 4 ft and no greater than 10 ft (3.05 m). Seas outside the predetermined limits forced rescheduling of the at-sea trials for safety and/or methodological reasons.

Safety of Personnel

During at-sea testing, measures were taken to insure that personnel were exposed to no risks beyond those normally experienced while operating during regular U.S. Coast Guard missions. Sea and weather conditions were checked and reports called in hourly while underway. In addition, an auxiliary safety coxswain/observer was on board during the heavy sea trials. During testing ashore, personnel were exposed to no known physical or psychological hazards. Any psychological stress due to taking the test battery was considered minimal and temporary.

DATA ANALYSIS

The various test trials listed below are referred to throughout the text in terms of the abbreviations in parentheses.

Test Trials

Calm Sea (Lake Pontchartrain)		*Heavy Sea (San Francisco Bay)*	
Terminal Baseline:	(Calm/TB)	Terminal Baseline:	(Heavy/TB)
At-Sea 1–2 hours:	(Calm/S2)	At-Sea 1–2 hours:	(Heavy/S2)
At-Sea 3–4 hours:	(Calm/S4)	At-Sea 3–4 hours:	(Heavy/S4)
At-Sea 5–6 hours:	(Calm/S6)	At-Sea 5–6 hours:	(Heavy/S6)
At-Sea 7–8 hours:	(Calm/S8)	At-Sea 7–8 hours:	(Heavy/S8)
At-Sea 9–10 hours:	(Calm/S10)	At-Sea 9–10 hours:	(Heavy/S10)
At-Sea 11–12 hours:	(Calm/S12)	At-Sea 11–12 hours:	(Heavy/S12)
At-Sea 13–14 hours:	(Calm/S14)	At-Sea 13–14 hours:	(Heavy/S14)
At-Sea 15–16 hours:	(Calm/S16)	At-Sea 15–16 hours:	(Heavy/S16)
Post-Test 1:	(Low/PT1)	Post-Test 1:	(Heavy/PT1)
Post-Test 2:	(Low/PT2)	Post-Test 2:	(Heavy/PT2)

Experimental Questions

Certain comparisons within Calm Sea and Heavy Sea, and between Calm and Heavy Seas were performed to answer 12 specific experimental questions, which are listed below. The results will be discussed in the context of these questions where significant changes in performance occurred due to trials.

QUESTION 1. Did fatigue degrade performance during the 16-hour mission? If so, at what point during the 16-hour mission did fatigue degrade performance? (Comparisons among Calm/S2 through Calm/S16, and among Heavy/S2 through Heavy/S16).

QUESTION 2. Was the fatigue decrement different for the two sea states? (Comparisons between Calm and Heavy at-sea tests).

QUESTION 3. Did motion with no fatigue affect performance? (Comparisons between Calm/TB and Calm/S2, and between Heavy/TB and Heavy/S2).

QUESTION 4. Did Heavy Sea motion produce different effects than Calm Sea motion with no fatigue? (Comparison between Calm/S2 and Heavy/S2).

QUESTION 5. Was the effect of fatigue plus motion greater than the effect of fatigue without motion? (Comparison between Calm/S16 and Calm/PT1, and between Heavy/S16 and Heavy/PT1).

QUESTION 6. Did fatigue with no motion degrade performance? (Comparison between Calm/PT1 and Calm/TB, and between Heavy/PT1 and Heavy/TB).

QUESTION 7. Were the effects of fatigue plus motion different between sea states after 16 hours? (Comparison between Calm/S16 and Heavy/S16).

QUESTION 8. Were the effects of fatigue with no motion different between sea states after 16 hours? (Comparison between Calm/PT1 and Heavy/PT1).

QUESTION 9. Was there a difference in recovery between sea states following 10 hours of rest/sleep? (Comparison between Calm/PT2 and Heavy/PT2).

QUESTION 10. Did recovery sleep/rest improve performance? (Comparison between Calm/PT1 and Calm/PT2, and between Heavy/PT1 and Heavy/PT2).

QUESTION 11. Was recovery performance the same as baseline performance? (Comparison between Calm/TB and Calm/PT2, and between Heavy/TB and Heavy/PT2).

QUESTION 12. Was baseline performance the same between sea states? (Comparison between Calm/TB and Heavy/TB).

Analysis of Variance

A two-factor repeated-measurement Analysis of Variance (ANOVA) was used to analyze each dependent measure. The first factor, Sea, contained two levels (calm and heavy). The second factor, Trials, contained 11 levels of testing: terminal baseline, eight at-sea, post-1, and post-2 trials. Greenhouse-Geisser probabilities are reported below for the F tests. This ANOVA allowed the investigation of the following main effects: Group (i.e., differences between the five Coast Guard subject groups), Sea, Trials; and the following interactions: Sea by Group, Group by Trials, Sea by Trials, and Sea by Trials by Group. The Duncan Multiple Range Test was used to analyze the main ANOVA significant F tests.

RESULTS

CRITICAL INSTABILITY TRACKING

Final Lambda

The mean final Lambda scores are presented in Figure 4. The ANOVA results indicated a significant Sea by Group interaction, F (4,12) = 6.14, p =.006 and a significant Trials effect, F (10,120), p <.0001. As shown in Figure 4, the general trend was a sharp decline in performance during Calm/S2 and Heavy/S2, followed by progressive improvement in performance during the remainder of the mission and the eventual re-establishment of the baseline performance level. *The pattern of the data supports an interpretation of "learning to perform in the motion environment."* A fatigue interpretation, based on the predicted outcome within the context of the 12 experimental questions, is not meaningful. Therefore, the 12 questions will not be discussed relative to the significant Trials effect. *For both sea states, relatively sharp decrements in performance occurred during the 15–16 hour test period*; however, the decreases were not significant.

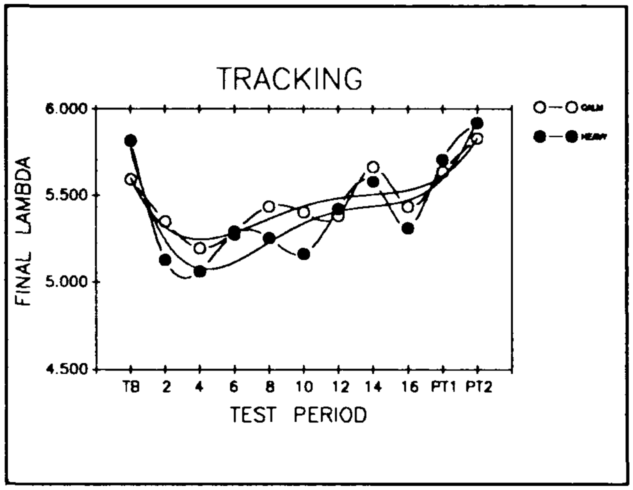

Figure 4. Tracking task final lambda as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post tests.

Root Mean Square (RMS) Error

The mean RMS scores are presented in Figure 5. The ANOVA indicated no significant effects. Sea state approached significance, $F\,(1,12) = 3.06$, $p = .11$. There appears to be a similar trend in the data across the two sea states: an initial performance improvement (decrease in RMS error), performance decrement, increment, then a decrement.

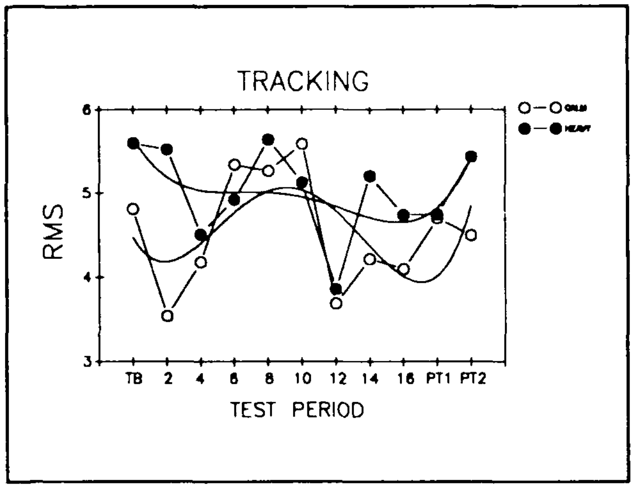

Figure 5. Tracking task root mean square error as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post tests.

Wall Hits

The mean Wall Hits scores are presented in Figure 6. The ANOVA indicated a significant Trials effect, $F\,(10,120) = 6.44$, $p = .0004$, and a significant Sea state by Group interaction, $F\,(4,12) = 7.31$, $p = .0032$. The significant interaction indicated that while the Sea state effect was significant, it affected the five groups differently. The Wall Hits scores presented an inverted mirror image of the tracking Final Lambda scores. Again, performance sharply worsened during the first at-sea test trials, then gradually improved during the rest of the mission. In both sea states, a *tendency for a decrement occurred during Calm/S16 and Heavy/S16 as compared to Calm/S14 and Heavy/S14, respectively. Also, Heavy/S16 was significantly different from Heavy/TB.* As with the Lambda scores, these data lend themselves more to a *learning to perform the task under motion* than to an interpretation in terms of fatigue. The Hits data will not be discussed in the context of the 12 experimental questions.

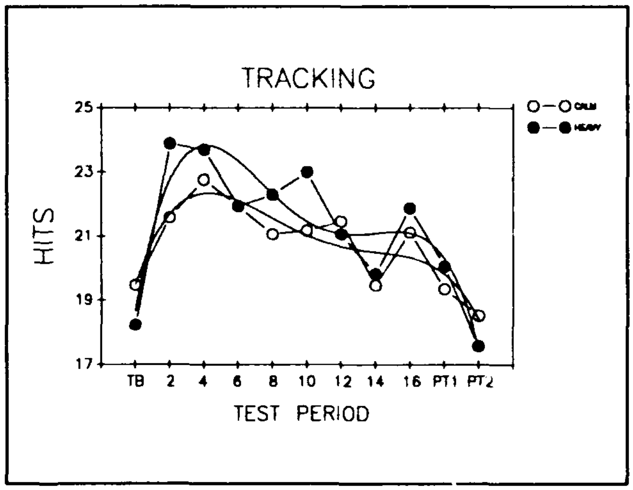

Figure 6. Tracking task hits as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post tests.

FOUR-CHOICE REACTION TIME

Reaction Time (RT)

The mean RT results are presented in Figure 7. Sea state significantly affected RT, $F(1,14) = 5.12$, $p = .04$. For Heavy Sea, RT =.452 seconds; for Calm Sea, RT =.432 seconds. Group effects approached significance, $F(4,14) = 2.88$, $p = .06$ with the Group means as follows: New Orleans RT =.422 seconds, Port Aransas RT =.506 seconds, Galveston RT =.435 seconds, San Francisco Group-1 RT =.440 seconds, and San Francisco Group-2 RT =.421 seconds. Trials produced significant effects, $F(10,140) = 2.62$, $p = .04$. The analysis of the significant Trials effect has particular relevance to the *a priori* comparisons required to answer the 12 experimental questions. The differences between Trial means within and across Sea state were analyzed for significance with the Duncan Multiple Range Test with the significance level set at $p \leq .05$.

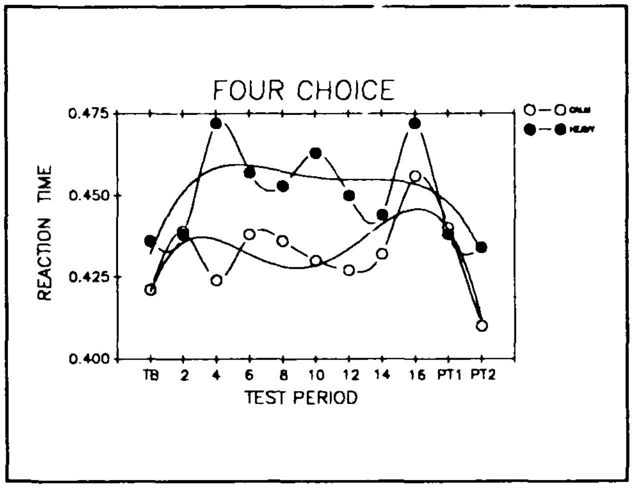

Figure 7. Four Choice task reaction time (sec) as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post tests.

QUESTION 1. Did fatigue degrade performance during the 16-hour mission? If so, at what point during the 16-hour mission did fatigue degrade performance? The results indicated no significant change in RTs for Calm Sea until Calm/S16; *during Calm/S16 a sharp increase in RT occurred* which was significantly greater than the RT obtained during Calm/S4. RTs for Calm/S2 through Calm/S14 were statistically the same. For Heavy Sea, *RT increased significantly during Heavy/S4*, then tended to decrease through Heavy/S14; *during Heavy/S16 RT increased again*. RT for Heavy/S16 was significantly greater than Heavy/S2.

QUESTION 2. Were the fatigue decrement points different for the two sea states? *Both Heavy and Calm Sea produced significant RT increases during the 15th and 16th hours at-sea.* The RTs for Calm/S16 and Heavy/S16 were significantly greater than Calm/S2 and Heavy/S2, respectively. However, the significant early increase in RT during Heavy/S4 as compared to Heavy/S2 indicated an initial decrement, gradual improvement, then a second decrement during Heavy/S16.

QUESTION 3. Did motion with no fatigue affect performance? No. The results indicated no difference between RTs for Calm/TB and Calm/S2, and between Heavy/TB and Heavy/S2. These comparisons reflect the single earliest performance measures obtainable during the mission for comparison with the baseline performance to provide the "purest" single comparison between motion with no (least amount) fatigue and baseline performance. This single comparison indicated no initial decrement due to motion. However, for Heavy Sea, Heavy/S4 RT was significantly greater than Heavy/S2. This indicated a relatively early decrement in Heavy Sea not evident in the Calm Sea.

QUESTION 4. Did Heavy Sea motion produce different effects than Calm Sea motion with no fatigue? No. The RTs for Calm/S2 and Heavy/S2 did not differ. This early comparison of performance between sea states indicated no difference due to motion prior to fatigue. However, the Sea state main effect was significant.

QUESTION 5. Was the effect of fatigue plus motion greater than the effect of fatigue without motion? The RTs for Calm/S16 and Calm/PT1 did not differ significantly; neither did RTs for Heavy/S16 and Heavy/PT1. However, the general trend was in the predicted direction of better performance under conditions of fatigue during no motion, rather than fatigue during motion.

QUESTION 6. Did fatigue with no motion degrade performance? No. The RTs for Calm/PT1 and Heavy/PT1 were not significantly worse than Calm/TB and Heavy/TB, respectively.

QUESTION 7. Were the effects of fatigue plus motion different between sea states after 16 hours? No. The RTs for Calm/S16 did not differ significantly from Heavy/S16. However, as noted above, the Sea state main effect was significant.

QUESTION 8. Were the effects of fatigue with no motion different between sea states after 16 hours? No. The RTs for Calm/PT1 did not differ from Heavy/PT1.

QUESTION 9. Was there a difference in recovery between sea states following 10 hours rest/sleep? No. Calm/PT2 RTs did not differ significantly from Heavy/PT2, although RT for Heavy/PT2 tended to be longer than Calm/PT2.

QUESTION 10. Did recovery sleep/rest improve performance? The RTs for Calm/PT1 and Calm/PT2 did not significantly differ, nor did Heavy/PT1 and Heavy/PT2; however, the trend was toward improvement following sleep/rest. The RTs for Calm/PT2 and Heavy/PT2 were significantly lower than Calm/S16 and Heavy/S16 RTs, respectively. These latter comparisons indicated that the combined improvement from Calm/S16 to Calm/PT2, and from Heavy/S16 to Heavy/PT2 was significant for both sea states.

QUESTION 11. Was recovery performance (Post-2 Trials) the same as baseline performance? Yes. Calm/TB RTs did not differ from Calm/PT2; RTs for Heavy/TB did not differ from Heavy/PT2.

QUESTION 12. Was baseline performance the same between sea states? Yes. The RTs for Calm/TB did not differ significantly with Heavy/TB RTs.

Percent Correct

The mean percent correct results are presented in Figure 8. The ANOVA indicated no significant effects. The Trials by Sea state cell means ranged from 99.16% to 100% correct. Group means ranged from 99.34% to 99.73% correct. These means indicated very high levels of accuracy across all test conditions for this task.

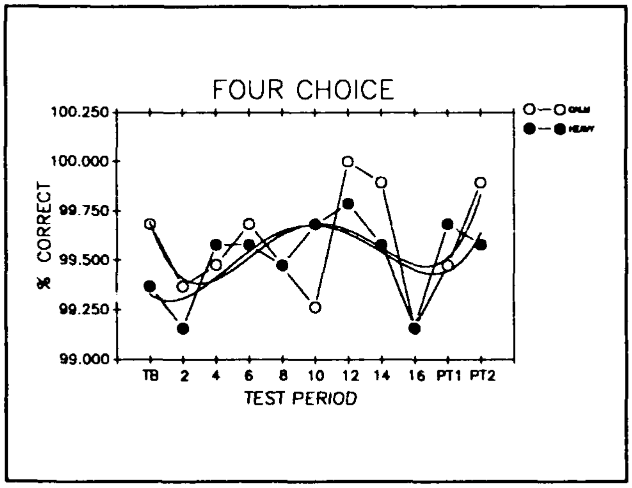

Figure 8. Four Choice task percent correct as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post tests.

MEMORY AND SEARCH TASK (MAST)

Response Time (RsT)

The MAST mean RsT data are presented in Figure 9. The ANOVA results indicated a significant Sea state by Group interaction, $F(4,14) = 4.59$, $p = .01$ and a significant Trials effect, $F(10,140) = 6.00$, $p = .0001$. Since the Trials effect is the critical main effect with regard to the fatigue-relevant 12 experimental questions, each question with relevant comparisons based on the Duncan Multiple Range Test is presented. The Sea state main effect was not significant.

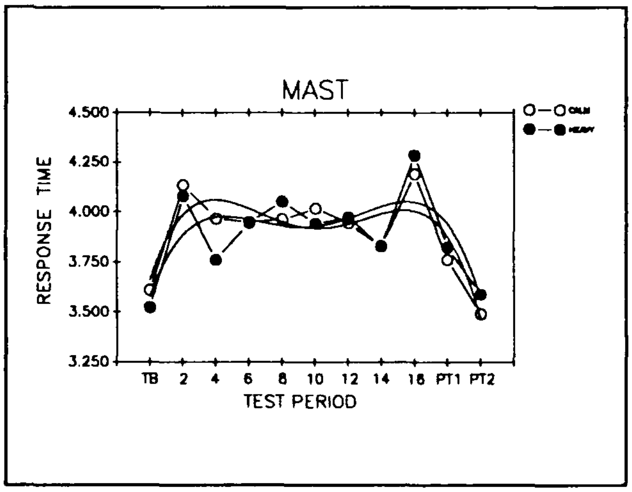

Figure 9. Memory and Search task response time (sec) as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post tests.

QUESTION 1. Did fatigue degrade performance during the 16-hour mission? If so, at what point during the 16-hour mission did fatigue degrade performance? For Calm Sea, no RsT significant differences occurred among the Calm/S2 through Calm/S16 trials, although Calm/S16 indicated a sharp, but not significant increase in RsT. For Heavy Sea, Heavy/S16 RsT was greater than Heavy/S4 and Heavy/S14 RsTs. Although, these results do not indicate clear-cut, unequivocal increments in fatigue during the 16-hour mission, *the sharp increases in RsTs during Calm / S16 and Heavy / S16 corroborated similar trends in performance decrements during the 15–16 hour at-sea trials with the Four-Choice Reaction Time Task and the Tracking Task.*

QUESTION 2. Was the fatigue decrement point different for the two sea states? No. *A similar trend occurred under the two sea states.*

QUESTION 3. Did motion with no fatigue affect performance? Yes. The RsTs for Calm/S2 and Heavy/S2 were significantly higher than RTs for Calm/TB and Heavy/TB, respectively.

QUESTION 4. Did Heavy Sea motion produce different effects than Calm Sea motion with no fatigue? No. The RsTs for Calm/S2 and Heavy/S2 were the same.

QUESTION 5. Was the effect of fatigue plus motion greater than the effect of fatigue without motion? Yes. The RsTs for Calm/S16 and Heavy/S16 were significantly greater than Calm/PT1 and Heavy/PT1, respectively.

QUESTION 6. Did fatigue with no motion degrade performance? Although the RsTs for Calm/PT1 and Heavy/TB were greater than Calm/TB and Heavy/TB, the differences were not significant; however, the trend was in the expected direction.

QUESTION 7. Were the effects of fatigue plus motion different between sea states after 16 hours? No. The RsTs for Calm/S16 and Heavy/S16 did not differ.

QUESTION 8. Were the effects of fatigue with no motion different between sea states after 16 hours? No. The RsTs for Calm/PT1 and Heavy/PT1 did not differ.

QUESTION 9. Was there a difference in recovery between sea states following 10 hours of rest/sleep? No. The RsTs for Calm/PT2 and Heavy/PT2 did not differ.

QUESTION 10. Did recovery sleep/rest improve performance? Yes. The RsT for Calm/PT2 was lower than Calm/PT1 RsT. For Heavy Sea a similar tendency was obtained, although the difference was not significant.

QUESTION 11. Was recovery performance the same as baseline performance? Yes. The RsTs for Calm/TB and Calm/PT2 did not differ; similarly, Heavy/TB and Heavy/PT2 did not differ.

QUESTION 12. Was baseline performance the same between sea states? Yes. The RsTs for Calm/TB and Heavy/TB did not differ.

Percent Correct

The MAST mean percent correct data are presented in Figure 10. The main ANOVA indicated only a significant Sea state effect, F (1,14) = 6.60, p =.02. These data indicate quite a high level of accuracy for this task under these difficult environmental conditions. For the means shown in Figure 10, accuracy ranged from 92.5% to 98% correct. Since no significant Trials effect was obtained the 12 experimental questions were not discussed.

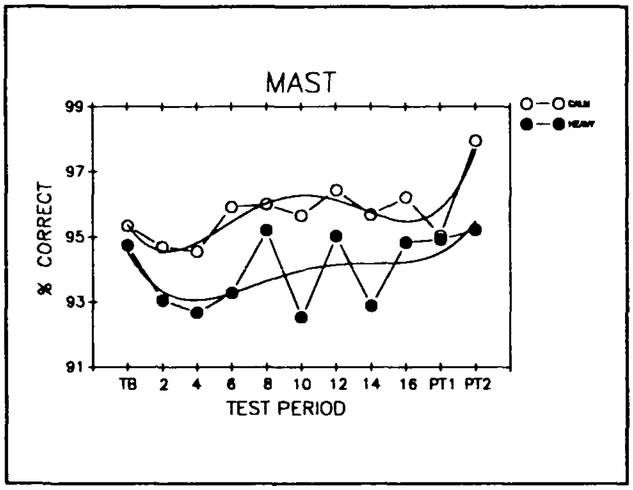

Figure 10. Memory and Search task percent correct as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post test.

MANUAL ASSEMBLY TASK

Upper Row Response Time (RsT)

The mean RsTs for the Upper Row task are presented in Figure 11. The ANOVA results indicated a significant Trials effect, F (10,110) = 2.39, p =.05. The Sea state by Trials interaction approached significance, F (10,110) = 1.72, p =.09. The Heavy Sea produced a significant increase in RsT from Heavy/TB to Heavy/S2. The Heavy/S6 RsT was significantly higher than Heavy/S4 and Heavy/TB RsTs. The Heavy/S16 RsT was significantly higher than Heavy/TB. No differences occurred within Calm Sea comparisons. The different effect for Trials for the two sea states reflects the near significant Sea state by Trials interaction. Heavy/PT2 RsTs were significantly less than Heavy/S2 and Heavy/S6. The *general trend* for the Manual Assembly Task Upper Row RsTs was similar to the critical tracking performance: *an initial performance decrement, probably due to a motion effect, followed by gradual performance improvement.* These results did not fit the 12 experimental

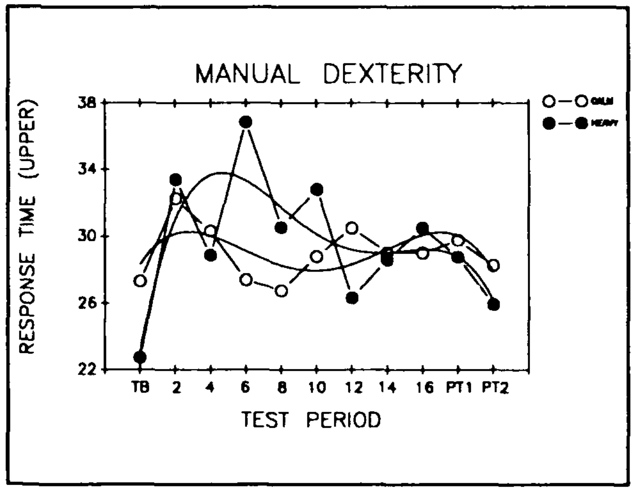

Figure 11. Manual Dexterity task response time (sec) as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post tests.

questions relevant to predicted fatigue effects; therefore, the data are not discussed with regard to those questions.

Lower Row Response Time (RsT)

The mean RsTs for the Lower Row Task are presented in Figure 12. The ANOVA results indicated a significant Sea state effect, F (1,11) = 12.32, p =.005; Heavy Sea produced longer RsTs. The Trials effect approached significance, F (10,110) = 2.37, p =.08; thus, the 12 experimental questions will not be discussed. However, the *general trend for Heavy Sea in Figure 12 is an abrupt increase in RsT during Heavy/S2 (probably due to motion); then improvement during Heavy/S4; then generally progressive decrements in performance with peak decrements occurring at Heavy/S10 and Heavy/S14.* Since the F test for Trials approached the p =.05 significance level, the Duncan multiple range test was performed. The Duncan test indicated: a significant increase in RsT for Heavy/S2 over Heavy/TB; the RsT for Heavy/S10 and Heavy/S14 were greater than Heavy/TB; and RsT for Heavy/S14 was greater than RsT for Heavy/S4. The Calm Sea condition produced a peak in RsTs during Calm/S10, similar to the Heavy Sea condition.

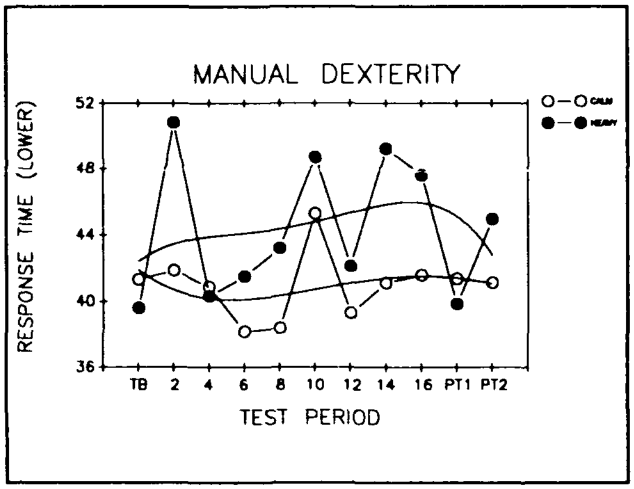

Figure 12. Manual Dexterity task response time (sec) as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post tests.

TWO-COLUMN ADDITION

Response Time (RsT)

The mean RsTs for the Two-Column Addition Task are presented in Figure 13. The ANOVA results indicated no significant effects. The *general tendency for both sea states were initial improvement in RsTs during the first two or three at-sea test trials, then gradual decrements,* which produced asymptotic levels below the baseline levels. The Heavy/PT2 and Calm/PT2 RsTs were in the direction of improved performance over the last at-sea trials. These data were not interpretable within our fatigue framework. The tendency suggested performance improvement during the mission, possibly due to *learning to perform in the motion environment.*

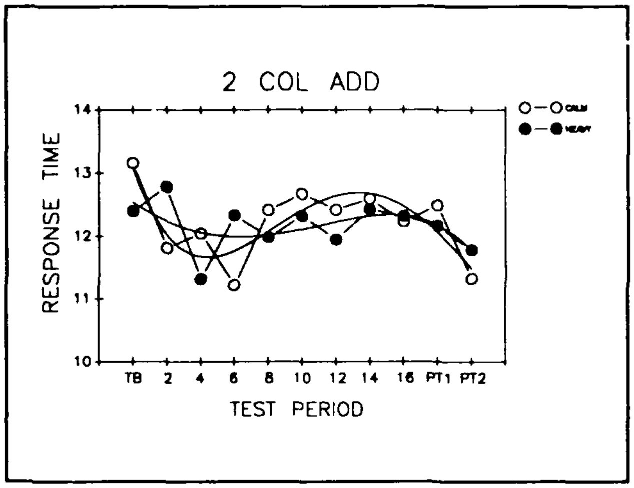

Figure 13. Two-Column Addition task response time (sec) as a function of test trial. TB = terminal baseline; At-sea testing = 2–16; PT = post tests.

Percent Correct

The mean percent correct scores for the Two-Column Addition Task are presented in Figure 14. The ANOVA results indicated a significant Sea state effect, $F\ (1,14) = 8.32$, $p = .01$ and a significant Sea state by Group interaction, $F\ (4,14) = 5.15$, $p = .009$. The Group main effect approached significance, $F\,(4,14) = 2.76, p = .07$. As evident in Figure 12, generally, the Heavy Sea produced poorer performance.

The results of the performance tests are summarized with regard to the 12 experimental questions in Table 1.

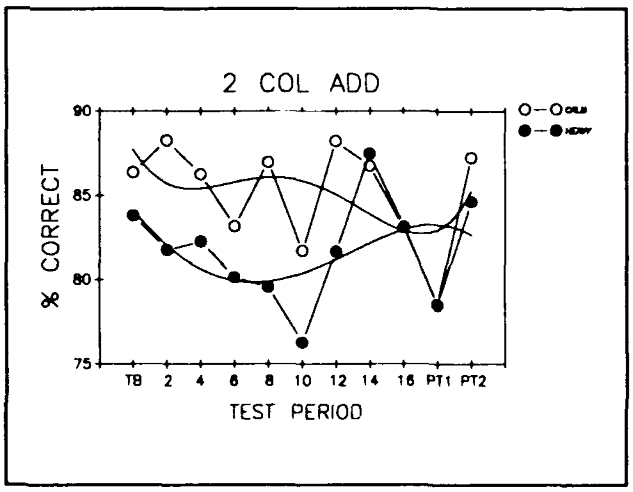

Figure 14. Two-Column Addition task percent correct as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post tests.

TABLE 1: Summary Results: Performance Tests

Experimental Questions	Critical Tracking			Four-Choice Reaction		MAST		Manual Assembly		Two-Column Addition	
	Lambda	RMS	Hit	RT	%	RT	%	Upper	Lower	RT	%
Q1. Did fatigue degrade performance? When?	N	N	N	Y S16	N	Y S16	N	N	(Y) S10 S14 S16	N	N
Q2. Was the fatigue decrement point different for Calm vs. Heavy Sea?	N	N	N	N	N	N	N	N	(Y)	N	N
Q3. Did motion without fatigue affect performance?	Y	N	Y	N	N	Y	N	Y	Y	N	N
Q4. Were effects different for H-Sea without fatigue vs. C-Sea without fatigue?	N	N	N	N	N	N	(Y)	N	Y	N	Y
Q5. Was the effect of fatigue with motion greater than fatigue without motion?	N	N	N	(Y)	N	Y	N	N	(Y)	N	N
Q6. Did fatigue without motion degrade performance?	N	N	N	N	N	N	N	N	N	N	N
Q7. Were the effects of fatigue with motion different for H-Sea vs. C-Sea after 16 hrs?	N	(Y)	N	(Y)	N	N	(Y)	N	Y	N	N
Q8. Were the effects of fatigue without motion different for H-Sea vs. C-Sea after 16 hrs?	N	N	N	N	N	N	N	N	N	N	N
Q9. Did recovery performance differ by sea state?	N	N	N	N	N	N	N	N	N	N	N
Q10. Did recovery after sleep/rest improve performance?	(Y)	N	(Y)	(Y)	N	Y	(Y)	(Y)	N	(Y)	(Y)
Q11. Was recovery performance the same as baseline performance?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
Q12. Was baseline performance the same for H-Sea and C-Sea?	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y

N = No; Y = Yes; (Y) = Tendency toward Yes; C = Calm; H = Heavy; S10 = at-sea 9–10 hrs; S14 = at-sea 13–14 hrs; S16 = at-sea 15–16 hrs; % = percent correct score; RT = reaction time.

STANFORD SLEEPINESS SCALE (SSS)

The mean SSS scores are presented in Figure 15. The SSS consists of seven descriptors of sleepiness which progressively increased from 1 to 7 in terms of degree of sleepiness. These scores (1–7) were averaged to compute mean SSS scores. The ANOVA results indicated a significant Trials effect, F (10,110) = 12.59, p =.0001 and a significant Group effect, F (3,11) = 5.23, p =.02. Sea state effects approached significance, F (1,11) = 3.58, p =.09. The SSS results will be discussed in the context of the 12 experimental questions.

For the subjective test scores, the wording of the 12 experimental questions was modified as appropriate to fit the particular test score under discussion.

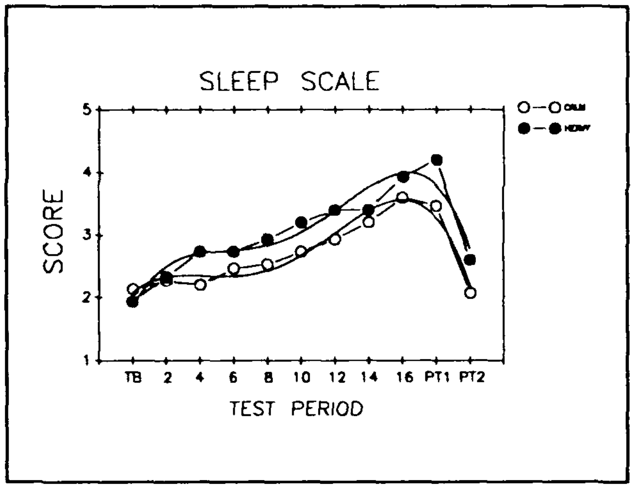

Figure 15. Sleep Scale Questionnaire mean score as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post tests.

QUESTION 1. Did sleepiness increase during the 16-hour mission? If so, at what point did it increase? Yes. Significant increases in sleepiness occurred during Calm/S2 through Calm/S16, as well as during Heavy/S2 through Heavy/S16. *For Heavy Sea, Heavy / S10 SSS scores were significantly higher than Heavy / S2 SSS scores. For Calm Sea, significant increases in sleepiness occurred later, during Calm / S14, relative to Calm / S2.*

QUESTION 2. Was the sleep increment point different for the two sea states? Yes. For Heavy Sea a significant increase in sleepiness occurred during Heavy/S10; for Calm Sea, sleepiness increased during Heavy/S14.

QUESTION 3. Did motion with no fatigue affect sleepiness? No. SSS scores for Calm/TB and Calm/S2 did not differ; neither did Heavy/TB and Heavy/S2.

QUESTION 4. Did Heavy Sea motion produce different sleepiness effects than Calm Sea motion with no fatigue? No. SSS scores for Calm/S2 did not differ from Heavy/S2.

QUESTION 5. Was sleepiness with motion greater than sleepiness without motion? No. SSS scores for Calm/S16 and Calm/PT1, and Heavy/S16 and Heavy/PT1 did not differ, respectively.

QUESTION 6. Was sleepiness during Post-1 testing greater than during baseline testing? Yes. SSS scores for Calm/PT1 were significantly greater than Calm/TB; similarly, Heavy/PT1 exhibited greater sleepiness than Heavy/TB.

QUESTION 7. Was sleepiness during motion different between sea states after 16 hours? No. SSS scores for Calm/S16 and Heavy/S16 did not differ.

QUESTION 8. Was sleepiness during no motion different between sea states after 16 hours? Yes. Heavy/PT1 SSS scores were higher than Calm/PT1.

QUESTION 9. Was there a difference in sleepiness recovery between sea states following 10 hours of rest/sleep? No. SSS scores for Calm/PT2 and Heavy/PT2 did not differ significantly.

QUESTION 10. Did recovery sleep/rest reduce sleepiness? Yes. SSS scores for Calm/PT2 were significantly lower than Calm/PT1; similarly, Heavy/PT2 scores were significantly lower than Heavy/PT1.

QUESTION 11. Was sleepiness following recovery the same as the baseline sleepiness level? Yes, for both Heavy Sea and Calm Sea. SSS scores for Calm/TB did not differ from Calm/PT2; Heavy/TB did not differ from Heavy/PT2.

QUESTION 12. Was the baseline sleepiness level the same between sea states? Yes. SSS scores for Calm/TB did not differ with Heavy/TB.

MOOD II QUESTIONNAIRE

Each of the six Mood II scales is presented individually. The mean Mood scores were calculated by averaging the following values and weighting them by frequency of response: 100% for "mostly or generally"; 50% for "somewhat or slightly"; and 0% for "not at all."

Fatigue

The mean fatigue ratings are presented in Figure 16. The ANOVA results indicated a significant Trials effect, F (10,150) = 15.41, p <.0001, and a significant Trials by Group effect, F (40,150) = 1.75, p =.04. The Sea state by Group interaction approached significance, F (4,15) = 2.70, p =.07.

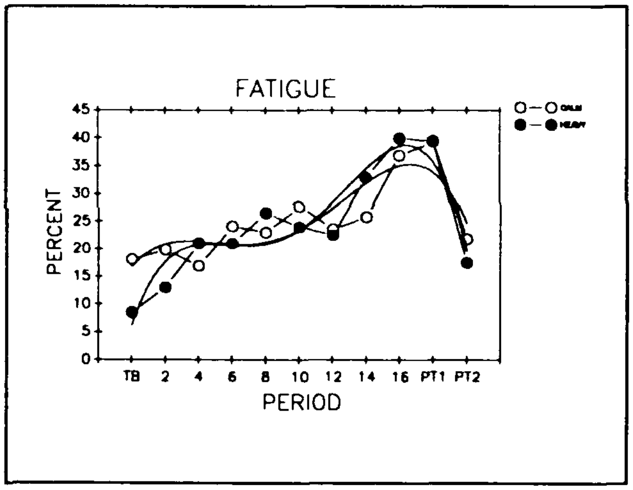

Figure 16. Mood II questionnaire, mean fatigue score as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post tests.

QUESTION 1. Did subjective fatigue increase during the 16-hour mission? If so, at what point did fatigue increase? *Subjective fatigue increased progressively during the mission.* For the Heavy Seas, by the fourth test trial, fatigue had increased significantly compared to the first trial. For Calm Seas, significant increase occurred during the eighth trial.

QUESTION 2. Was the fatigue increment different for the two sea states? Yes. *For Heavy Sea*, a significant increase in fatigue over Heavy/S2 occurred *during Heavy/S8*. *For Calm Sea*, fatigue measured *during Calm/S16* was significantly greater than at Calm/S2.

QUESTION 3. Did motion produce a significant increase in fatigue? No difference in fatigue occurred between Calm/TB and Calm/S2; neither was there a difference between Heavy/TB and Heavy/S2.

QUESTION 4. Did Heavy Sea motion produce different fatigue effects than Calm Sea motion during the first at-sea test trial? No. No significant differences in fatigue due to different Sea states occurred during the first at-sea trials; i.e., Calm/S2 and Heavy/S2 did not differ.

QUESTION 5. Was perceived fatigue greater during motion than not during motion? No. There were no differences between fatigue at Heavy/S16 and Heavy/PT1, or between Calm/S16 and Calm/PT1.

QUESTION 6. Did fatigue persist during no motion following the 16-hour mission? Yes. Fatigue without motion was significantly greater than the baseline fatigue level: Heavy/PT1 and Calm/PT1 were greater than Heavy/TB and Calm/TB, respectively.

QUESTION 7. Was fatigue during motion at the end of the 16-hour mission different between sea states? No. There were no fatigue differences between Sea states after 16 hours: Heavy/S16 and Calm/S16 were not different.

QUESTION 8. Was fatigue during no motion different between sea states after 16 hours? No. There were no fatigue differences between Heavy/PT1 and Calm/PT1.

QUESTION 9. Was there a difference in fatigue recovery between sea states following 10 hours of rest/sleep? No. There were no differences between Heavy/PT2 and Calm/PT2.

QUESTION 10. Did recovery sleep/rest reduce fatigue? Yes. For both sea states there were significant increases in recovery from fatigue between Post-1 and Post-2 testing.

QUESTION 11. Was fatigue level during recovery testing the same as during baseline testing? Yes. Fatigue at Post-2 testing did not differ significantly from the respective baseline levels.

QUESTION 12. Were baseline fatigue scores the same between sea states? No. Baseline fatigue level for the Calm Sea state was greater than for Heavy Seas; why this was the case, is not known.

Activity

The mean activity ratings are presented in Figure 17. The ANOVA results indicated a significant Trials effect, $F\ (10,150) = 11.86$, $p < .0001$; Trial by Group interaction, $F\ (40,150) = 1.89$, $p = .03$; and Sea state by Trials interaction, $F\ (10,150) = 2.72$, $p .03$.

QUESTION 1. Did activity decrease during the 16-hour mission? If so, at what point during the mission did activity decrease? *Perceived activity decreased progressively for Heavy and Calm Sea during the 16-hour mission.* The significant Sea state by Trials interaction is evident in Figure 17 in that the decrease in activity over trials differed for Heavy and Calm Sea. The activity for the two sea conditions was the same during baseline and initial at-sea test trials, then diverged during the later trials during the mission. Heavy Sea activity was less during Heavy/S6 through

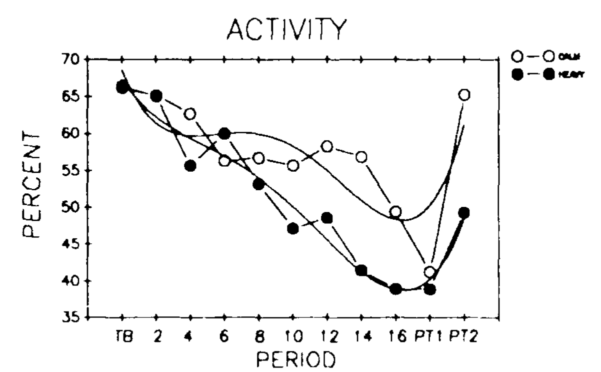

Figure 17. Mood II questionnaire, mean activity scores as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post tests.

Heavy/S16 compared with Calm/S6 and Calm/S16.

QUESTION 2. Was the activity decrement point different for the two sea states? Yes. Subjective *activity for Heavy Sea at Heavy / S8 was significantly less than activity at Heavy / S2* and continued to decrease. *For Calm Sea, activity decreased at a significantly lower rate.* Activity for Heavy/S14 and Heavy/S16 were significantly lower than for Calm/S14 and Calm/S16. *Perceived activity was less from the fourth through the eighth at-sea test trial Heavy Sea compared to Calm Sea.*

QUESTION 3. Did motion with no fatigue significantly decrease activity? No. Calm/TB and Heavy/TB did not differ with Calm/S2 and Heavy/S2, respectively.

QUESTION 4. Did Heavy Sea motion produce different activity scores than Calm Sea motion with no fatigue (i.e., during the first at-sea test trial)? No. Activity for Calm/S2 and Heavy/S2 did not differ.

QUESTION 5. Did motion alone affect feelings of activity after 16 hours at sea? No, activity scores for Calm Sea Calm/PT1 and Calm/S16 were the same. For Heavy Sea, activity continued to decrease significantly from Heavy/S16 to Heavy/PT1.

QUESTION 6. Was activity during Post-1 testing less than during baseline testing? Yes, for both sea states.

QUESTION 7. Was activity during motion different between sea states after 16 hours? Yes. Activity for Heavy/S16 was less than for Calm/S16.

QUESTION 8. Was activity during no motion different between sea states after 16 hours? No. Activity scores for Heavy/PT1 and Calm/PT1 did not differ.

QUESTION 9. Was there a difference in activity recovery between sea states following 10 hours of rest/sleep? Yes. Activity scores for Heavy/PT2 were significantly lower than for Calm/PT2.

QUESTION 10. Did recovery sleep/rest increase activity scores? Yes. Activity scores for Calm/PT2 were significantly greater than scores for Calm/PT1. Activity scores for Heavy/PT2 increased over Heavy/PT1, although the increment was not significant.

QUESTION 11. Were activity scores following recovery (i.e., at Post-2) the same as at baseline? Yes, for Calm Sea. For Heavy Sea, Heavy/PT2 was still significantly lower than Heavy/TB.

QUESTION 12. Was activity during baseline testing the same between sea states? Yes. Heavy/TB and Calm/TB did not differ.

Happiness

The mean subjective happiness scores are presented in Figure 18. The ANOVA results indicated a significant Trials effect, $F\,(10,150) = 7.27, p < .0001$.

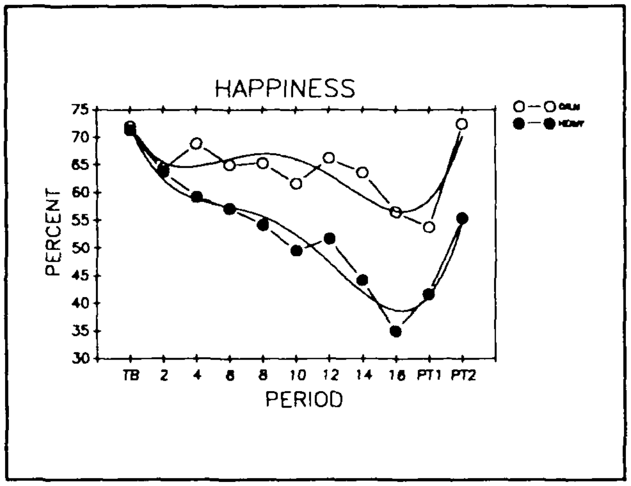

Figure 18. Mood II questionnaire, mean happiness score as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post tests.

QUESTION 1. Did feelings of happiness decrease during the 16-hour mission? If so, at what point did happiness decrease? *The trend for both Sea states was a progressive decrease in feelings of happiness during the 16-hour mission.*

QUESTION 2. Was the happiness decrement point different for the two sea states? Yes. Feelings of happiness diverged as a function of Sea state from the second at-sea test trial onward. *Happiness feelings for the sixth, seventh, and eighth trials were significantly less for Heavy Sea.*

QUESTION 3. Did motion alone significantly decrease happiness? No. Calm/TB and Heavy/TB did not differ with Calm/S2 and Heavy/S2, respectively.

QUESTION 4. Did Heavy Sea motion produce different happiness scores than Calm Sea motion *with no fatigue (i.e., during the first at-sea test trial)*? No. Happiness for Calm/S2 and Heavy/S2 did not differ.

QUESTION 5. Did motion alone following 16 hours at-sea affect feelings of happiness? No. There were no differences between Calm/S16 and Calm/PT1, and between Heavy/S16 and Heavy/PT1

QUESTION 6. Was happiness during no motion, immediately following the 16-hour mission (Post-1 testing), different from the baseline level? Yes. For both Sea states happiness measured during Post-1 was less than during baseline.

QUESTION 7. Was happiness during motion different between sea states after 16 hours? Yes. Happiness for Calm/S16 was greater than for Heavy/S16.

QUESTION 8. Was happiness during no motion different between sea states after 16 hours? No. Although the mean happiness ratings for Heavy/PT1 were lower, the difference between Heavy/PT1 and Calm/PT1 was not significant.

QUESTION 9. Was there a difference between sea states in happiness recovery following 10 hours of rest/sleep? Yes. Happiness for Calm/PT2 was greater than for Heavy/PT2.

QUESTION 10. Did recovery sleep/rest increase happiness scores? Yes. For both Sea states, happiness at Post-2 testing were greater than for Post-1.

QUESTION 11. Were happiness scores following recovery (i.e., at Post-2) the same as at baseline? Yes.

QUESTION 12. Was happiness during baseline testing the same between sea states? Yes.

Anger

The mean subjective anger scores are presented in Figure 19. The ANOVA results indicated a significant Trials effect, $F(10,150) = 7.52, p = .0002$.

QUESTION 1. Did feelings of anger increase during the 16-hour mission? If so, at what point did anger increase? *The trend for both Sea states was a progressive increase in feelings of anger during the 16-hour mission.*

QUESTION 2. Was the anger increment point different for the two sea states? *Feelings of anger increased in a similar pattern across sea states.* For both sea states feelings of anger across baseline through the seventh at-sea test trial did not differ. There was a sharp *increase in anger during the last at-sea test trial.*

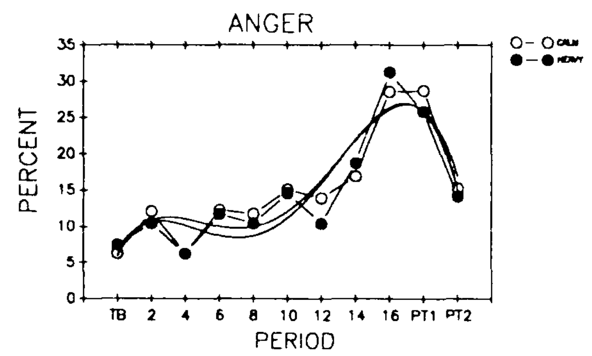

Figure 19. Mood II questionnaire, mean anger score as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post tests.

QUESTION 3. Did motion alone significantly increase anger? No. Calm/TB and Heavy/TB did not differ with Calm/S2 and Heavy/S2, respectively.

QUESTION 4. Did Heavy Sea motion produce different anger feelings than Calm Sea motion with no fatigue (i.e., during the first at-sea test trial)? No. Anger for Calm/S2 and Heavy/S2 did not differ.

QUESTION 5. Did motion alone following 16 hours at-sea affect feelings of anger? No. There were no differences between Calm/S16 and Calm/PT1, and between Heavy/S16 and Heavy/PT1

QUESTION 6. Was anger during no motion, immediately following the 16-hour mission (Post-1 testing), different from the baseline level? Yes. For both sea states anger measured during Post-1 was greater than during baseline.

QUESTION 7. Was anger during motion different between sea states after 16 hours? No. Anger for Calm/S16 and Heavy/S16 did not differ.

QUESTION 8. Was anger during no motion different between sea states after 16 hours? No. Anger for Heavy/PT1 and Calm/PT1 did not differ.

QUESTION 9. Was there a difference between sea states in anger recovery following 10 hours of rest/sleep? No. Anger for Calm/PT2 and Heavy/PT2 did not differ.

QUESTION 10. Did recovery sleep/rest decrease anger scores? Yes. For both Sea states, anger decreased from Post-1 to Post-2 testing. The difference was significant for Calm Sea and approached significance for Heavy Sea.

QUESTION 11. Were anger scores following recovery (i.e., at Post-2) the same as at baseline? Yes.

QUESTION 12. Was anger during baseline testing the same between sea states? Yes

Fear

The mean subjective fear scores are presented in Figure 20. The ANOVA results showed no significant effects. As indicated in Figure 18, feelings of fear remained low throughout the two missions.

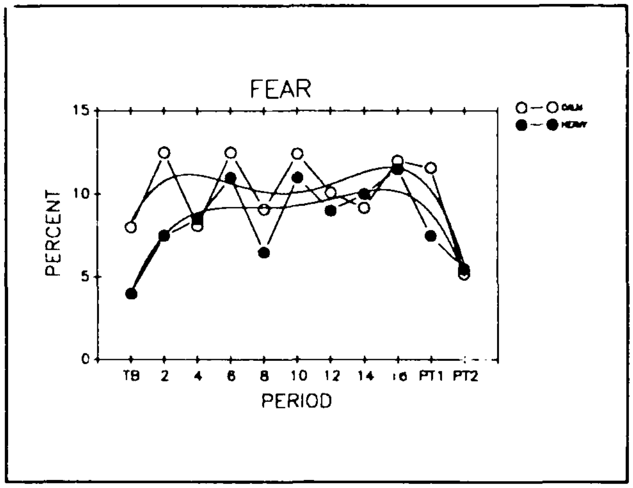

Figure 20. Mood II questionnaire, mean fear score as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post tests.

Depression

The mean subjective depression scores are presented in Figure 21. The ANOVA results indicated a significant Trials effect, $F\,(10,150) = 2.94, p = .03$.

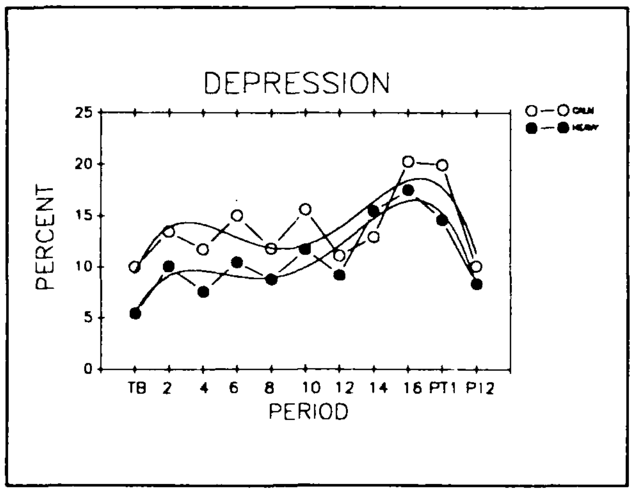

Figure 21. Mood II questionnaire, mean depression score as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post test.

QUESTION 1. Did feelings of depression increase during the 16-hour mission? If so, at what point did depression increase? The trend for both Sea states was a *gradual increase in feelings of depression during the first 12 hours, with greater increases during the last four hours of the mission.* Except for the seventh at-sea trial, Calm Sea depression scores were always greater than Heavy Sea.

QUESTION 2. Was the depression increment point different for the two sea states? *Generally, feelings of depression increased in a similar pattern across sea states.* For Heavy Sea, a sharp increment occurred during Heavy/S14 that was significantly greater than Heavy/TB. For Calm Sea a similar significant increment occurred during Calm/S16.

QUESTION 3. Did motion alone significantly increase depression? No. Calm/TB and Heavy/TB did not differ with Calm/S2 and Heavy/S2, respectively.

QUESTION 4. Did Heavy Sea motion produce different depression scores than Calm Sea motion with no fatigue (i.e., during the first at-sea test trial)? No. Depression for Calm/S2 and Heavy/S2 did not differ.

QUESTION 5. Did motion alone, following 16 hours at sea, affect feelings of depression? No. There were no differences between Calm/S16 and Calm/PT1, and between Heavy/S16 and Heavy/PT1

QUESTION 6. Was depression during no motion, immediately following the 16-hour mission (Post-1 testing), different from the baseline level? For the Calm Sea, Post-1 trial depression was significantly greater than baseline. For Heavy Sea, Post-1 trial depression was not significantly greater than baseline, although the tendency was in the expected direction.

QUESTION 7. Was depression during motion different between sea states after 16 hours? No. Depression for Calm/S16 and Heavy/S16 did not differ.

QUESTION 8. Was depression during no motion different between sea states after 16 hours? No. Depression for Heavy/PT1 and Calm/PT1 did not differ.

QUESTION 9. Was there a difference between sea states in depression recovery following 10 hours of rest/sleep? No. Depression for Calm/PT2 and Heavy/PT2 did not differ.

QUESTION 10. Did recovery sleep/rest decrease depression scores? Yes. For both Sea states, depression decreased from Post-1 to Post-2 testing. The difference was significant for Calm Sea and approached significance for Heavy Sea.

QUESTION 11. Were depression scores following recovery (i.e., at Post-2) the same as at baseline? Yes.

QUESTION 12. Was depression during baseline testing the same between sea states? Yes.

MOTION SICKNESS SYMPTOMATOLOGY (MSS) CHECKLIST

The mean responses to the 24 MSS descriptor phrases are presented in Figure 22. MSS scores were computed by averaging the 24 scores from 0–3 for the 24 symptoms. The ANOVA results indicated a significant Sea state effect, $F\,(1,14) = 4.67$, $p = .05$ and a significant Trials effect, $F\,(10,140) = 10.57$, $p < .0001$. The Sea state by Trials interaction approached significance, $F\,(10,140) = 2.40$, $p = .06$. Due to the significant Trials effect, these results will be discussed in the context of the 12 experimental questions.

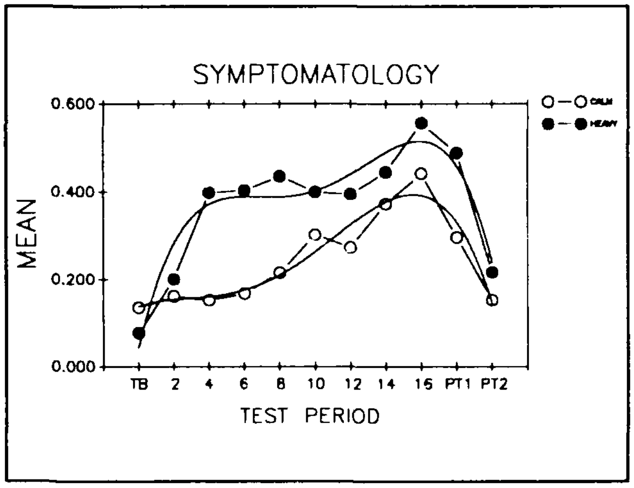

Figure 22. Motion Sickness Symptomatology score as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post test.

QUESTION 1. Did MSS increase during the 16-hour mission? Yes. If so, at what point during the 16-hour mission did MSS increase? *MSS increased progressively during the mission.* For Heavy Seas, MSS at *Heavy/S4* was significantly greater than Heavy/S2. For Calm Seas, MSS at *Calm/S14* was greater than Calm/S2.

QUESTION 2. Was the MSS increment point different for the two sea states? Yes. *For Heavy Seas, MSS at Heavy/S4 was significantly greater than Heavy/S2. For Calm Seas, MSS at Calm/S14 was greater than Calm/S2.*

QUESTION 3. Did motion with no fatigue significantly increase MSS? No. Calm/TB and Calm/S2 did not differ; similarly, Heavy/TB and Heavy/S2 did not differ.

QUESTION 4. Did Heavy Sea motion produce different MSS scores than Calm Sea motion with no fatigue? No. Calm/S2 and Heavy/S2 did not differ.

QUESTION 5. Was the effect on MSS of fatigue plus motion greater than the effect of fatigue without motion? No. Calm/S16 and Calm/PT1 did not differ; neither did Heavy/S16 and Heavy/PT1.

QUESTION 6. Was MSS during Post-1 testing greater than during baseline testing? Yes. Calm/PT1 MSS was greater than Calm/TB; similarly, Heavy/PT1 was greater than Heavy/TB.

QUESTION 7. Was MSS during motion different between sea states after 16 hours? Although Heavy/S16 MSS scores tended to be higher than Calm/S16, the difference was not significant.

QUESTION 8. Was MSS during no motion different between sea states after 16 hours? Yes. Heavy/PT1 MSS was greater than Calm/PT1.

QUESTION 9. Was there a difference in MSS recovery between sea states following 10 hours of rest/sleep? No. Calm/PT2 MSS and Heavy/PT2 did not differ.

QUESTION 10. Did recovery sleep/rest reduce MSS? Yes, Heavy/PT2 MSS scores were lower than Heavy/PT1. For Calm Seas, Calm/PT2 MSS scores were not lower than Calm/PT1.

QUESTION 11. Was MSS level following recovery the same as at baseline? Yes. Calm/TB and Calm/PT2 did not significantly differ; neither did Heavy/TB and Heavy/PT2.

QUESTION 12. Was MSS during baseline testing the same between sea states? Yes. Calm/TB MSS and Heavy/TB did not differ.

MOTION SICKNESS MAGNITUDE (MSM) ESTIMATE

The MSM estimate was a single, overall estimate of one's general feeling regarding motion sickness. The mean MSM estimates are presented in Figure 23. The ANOVA results indicated a significant Sea state effect, $F\ (1,14) = 22.04$, $p = .0003$; a significant Trials effect, $F\ (10,140) = 7.65$, $p = .0001$; and a significant Sea state by Trials interaction, $F\ (10,140) = 3.24$, $p = .02$. These results are discussed in the context of the 12 experimental questions.

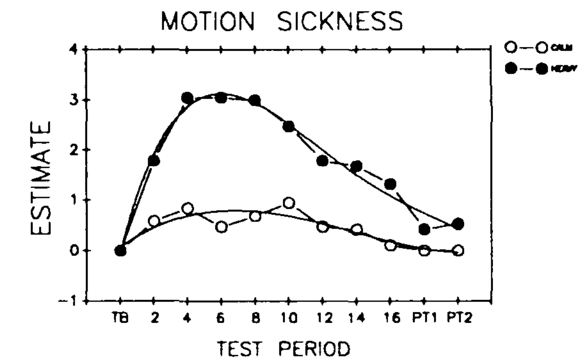

Figure 23. Motion Sickness Magnitude Estimate as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post tests.

QUESTION 1. Did MSM increase during the 16-hour mission? If so, at what point during the 16-hour mission did MSM increase? *Yes, for Heavy Seas only, MSM increased significantly during the mission.* MSM for Heavy/S2 was significantly greater than Heavy/TB; Heavy/S4 was significantly greater than Heavy/S2.

QUESTION 2. Was the MSM increment point different for the two sea states? *Yes. Only for Heavy Seas was there significant changes in MSM.*

QUESTION 3. Did motion with no fatigue affect MSM? Yes, for Heavy Seas, Heavy/S2 experienced greater MSM than Heavy/TB.

QUESTION 4. Did Heavy Sea motion produce different MSM scores than did Calm Sea motion with no fatigue? Yes. Heavy/S2 MSM scores were significantly greater than Calm/S2.

QUESTION 5. Was the effect on MSM of fatigue plus motion greater than the effect of fatigue without motion? No. No differences resulted between Calm/S16 and Calm/PT1; and between Heavy/S16 and Heavy/PT1.

QUESTION 6. Was MSM during Post-1 testing greater than during baseline testing? No differences resulted between Calm/PT1 and Calm/TB or between Heavy/PT1 and Heavy/TB.

QUESTION 7. Was MSM during motion different between sea states after 16 hours? Yes. Heavy/S16 MSM scores were higher than Calm/S16.

QUESTION 8. Was MSM during no motion different between sea states after 16 hours? No. Calm/PT1 and Heavy/PT1 did not differ.

QUESTION 9. Was there a difference in MSM recovery between sea states following 10 hours of rest/sleep? No. Calm/PT2 and Heavy/PT2 did not differ.

QUESTION 10. Did recovery sleep/rest reduce MSM? No. There were no differences between Calm/PT1 and Calm/PT2; and Heavy/PT1 and Heavy/PT2.

QUESTION 11. Was MSM level following recovery the same as at baseline? Yes. There were no differences between Calm/TB and Calm/PT2; and Heavy/TB and Heavy/PT2.

QUESTION 12. Was MSM during baseline testing the same between sea states? Yes. Calm/TB and Heavy/TB did not differ.

MOTION MAGNITUDE (MM) ESTIMATE

The mean MM estimates are presented in Figure 24. The results of the ANOVA indicated a significant Sea state effect, $F(1,14) = 35.66$, $p < .0001$; Trials effect, $F(10,140) = 65.37$, $p < .0001$; and Sea state by Trials interaction, $F(10,140) = 8.26$, $p < .0001$. These results show that the participants accurately judged the relative motion between sea conditions, and did so throughout the missions. These data will not be discussed with reference to the 12 experimental questions.

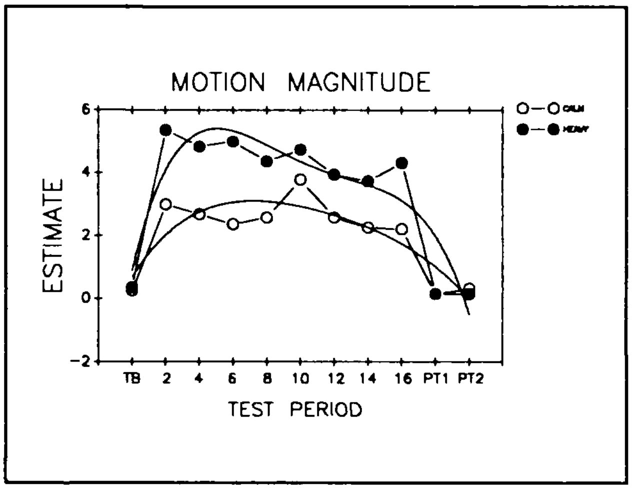

Figure 24. Motion Magnitude Estimate as a function of test trial. TB = terminal baseline; at-sea testing = 2–16; PT = post tests.

DISCUSSION

The performance test results can be categorized into three groups: (1) tests which indicated fatigue effects on performance, (2) tests which indicated disruptive motion effects on performance, and (3) tests which showed no effects.

The Four-Choice Reaction Time (RT), MAST (RsT), and the Manual Assembly (lower row RsT, Heavy Sea) showed evidence that fatigue may have degraded performance. These three performance measures indicated a performance decrement during the 15–16 hour at-sea period. In addition, the Manual Assembly lower row RsT showed decrements during the 9–10 and 13–14 hour at-sea test periods. It must be noted, however, that for these three tests, a significant motion (with no fatigue) effect was also obtained. The motion (with no fatigue) effect was the difference in performance between the terminal baseline performance and the first at-sea test trial performance (which should have included the least amount of fatigue during motion possible in this study). None of these tests showed a significant fatigue without motion effect; i.e., a difference in performance between the terminal baseline test trials (Calm/TB and Heavy/TB) and the dockside testing immediately following the mission (Calm/PT1 and Heavy/PT2). These three test measures indicated that performance during fatigue with motion was worse than performance during fatigue without motion; this was the difference between the last at-sea test trial (Calm/S16 and Heavy/S16) and the dockside testing immediately following the mission (Calm/PT1 and Heavy/PT2).

The Tracking Task data indicated that motion, per se, degraded performance (Lambda and Wall Hits) during the first at-sea test trial; performance gradually improved throughout the remainder of the mission. It is unclear why the initial motion disruption in performance was not followed by further progressive deterioration in performance instead of progressive improvement. The tracking measures indicated that, rather than having their performance degrade as a result of fatigue, subjects learned to perform the task under motion conditions. The Manual Assembly Task, upper row RsT, also showed a disruptive motion effect on performance during the initial at-sea test trial, followed by a general performance improvement trend.

The Two-Column Addition Task indicated no effects due to either motion or fatigue.

Generally, the Heavy Sea condition produced poorer performance during the at-sea test trials. Where initial disruptive motion effects on performance were obtained, the effects were greater in the Heavy Sea condition.

The subjective test measures provided extremely systematic variations due to time-of-day and sea state effects. As would be expected, greater motion sickness symptoms and higher general ratings of motion sickness occurred during Heavy Sea. Subjects consistently estimated the motion of the Heavy Sea to be greater than the motion of the Calm Sea. Greater feelings of sleepiness occurred during Heavy Sea than during Calm Sea. The Mood II data also produced expected systematic changes in the individual mood scales. The fatigue scale showed progressive feelings of increasing fatigue from the first through the last at-sea test trial, and continuing during the first Post-Test session. No difference occurred due to sea states. Increases in feelings of anger and depression produced trends similar to fatigue. Feelings of happiness and activity level decreased progressively during the at-sea test trials.

During the latter test trials, significant differences in happiness and activity feelings occurred due to sea state; Calm Sea resulted in more happiness and greater activity feelings. The test subjects exhibited extremely low levels of fear feelings, which did not change during the test trials.

The present results are similar to those reported by Royal and Needalman [2], who found no performance effects due to cumulative time underway (CTUW) but did find subjective measures to co-vary with CTUW. They used the following performance tests, which were part of the Automated Portable test System administered via a NEC microcomputer: finger-tapping speed, two-handed tapping speed, code substitution, pattern recognition, and grammatical reasoning. Their subjective rating measures included items similar to the six Mood II Questionnaire scales. Their Subjective Fatigue Ratings increased with increasing CTUW. The following Mood Adjective Checklist items increased with increasing CTUW: "tired," "sluggish," "sleepy." Royal and Needalman also found the following Midwest Research Institute mood scale items to increase with increasing CTUW: "fatigued" and "drowsy"; and they found the following items to decrease with increasing CTUW: "energetic" and "enthusiastic." The subjective data obtained in the present report agree with the findings of Royal and Needalman.

CONCLUSIONS AND RECOMMENDATIONS

1. The present performance data generally indicated no severe decrements in performance during the 16-hour missions in the 41-ft UTB. Where *both fatigue and motion decrement* effects were obtained, *these degrading effects occurred during the* 9–16 *hour part of the* mission.

2. Subjective feelings of positive effects (happiness, activity) decreased systematically during the mission. Conversely, feelings of negative effects (anger, fatigue, sleepiness, depression) increased systematically during the mission. These increased and decreased patterns were consistent with findings of other researchers.

3. Sea state produced significant effects on certain performance tests and most of the subjective measures.

4. The present data generally indicated no significant fatigue effects on performance throughout the 16-hour simulated operational mission. However, certain degrading effects in performance began to appear 9 to 10 hours into the mission. Therefore, the results of this study support the existing boat crew scheduling guidelines as specified in COMMANDANT INSTRUCTION 5312.15A, which recommends that crew underway times not exceed 10 hours for seas less than 4 ft or 8 hours for seas greater than 4 ft.

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